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General Editor:

WILLIAM BRIGGS, LL.D., D.C.L., M.A., B.Sc.

Principal of University Correspondence College.

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BOTANY
FOR MATRICULATION.

BY

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PREFACE.

IN preparing this book I have used freely my previous works, *Plant Biology* and *Life Histories of Common Plants*, but at the same time a very large portion of the text is new.

The fact that I regard Ecology (the study of adaptation to environment) and Physiology as the aspects of Plant Life which should be chiefly presented to beginners will explain and, I hope, justify the inclusion in this book of a good deal of information which is given in works on Chemistry, Physics, Meteorology, and Geology. I do not think the bringing together of the facts dealt with in Chapter II is at all out of place in a book on Plant Life The plant is a living and sentient being, acted upon, responding to, and influenced by, all the factors which make up its environment, it is the central figure upon which many external forces play It is impossible to get a clear picture of the adaptations of a plant without carefully studying its natural surroundings and also experimenting with it under controlled conditions

The essence of good teaching in Elementary Botany is to bring the student into the closest personal contact with the fundamental facts of the science Accordingly I have inserted in this book a very large number of experiments, and also very full directions for the examination and sketching of specimens As some teachers will find that the time which their classes can devote to the subject does not allow them to perform all the experiments here given, those experiments which are of fundamental importance have been indicated with an asterisk

In the Chapters on the Natural Orders some paragraphs have been enclosed in square brackets. This is to indicate that the plants described are not found growing *wild* in Britain, but are commonly cultivated in gardens, shrubberies, or plantations

For the loan of certain illustration-blocks I am indebted to the courtesy and kindness of Messrs Baird and Tatlock, Cross Street, Hatton Garden, London, E.C , the Council of the Linnean Society, Dr T W. Woodhead, Dr W. G. Smith; and my colleague Mr E R Marle

Messrs Clive and Co have prepared an excellent set of microscopical preparations (*Plant Biology Set of Micro. Slides*, price 25*s*), which will be found to answer admirably for use with this book , the set is accompanied by a descriptive booklet.

I shall be very glad to receive suggestions and criticisms from teachers and others who use this book

F CAVERS.

HARTLEY UNIVERSITY COLLEGE,
SOUTHAMPTON.

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MATRICULATION BOTANY.

CHAPTER I.

INTRODUCTION—THE BROAD BEAN PLANT.

1. Seed Plants.—In this book we shall study only the higher plants, which produce flowers and seeds and are therefore called the Flowering Plants or Seed Plants, to distinguish them from the lower plants which do not produce seeds—Ferns, Mosses, Fungi, Seaweeds, etc

Most Seed Plants agree in certain general features of form and structure, though showing endless differences in details

2. Practical Work.—Get all the seeds, plants, and other materials mentioned in the directions for practical work and carry out the directions faithfully, making observations and experiments for yourself and keeping a careful record of your work written in your own words and illustrated by your own drawings from actual objects

3. Sketches Required.—It is of the utmost importance that, besides keeping a written record of all your observations and experiments, you should make careful drawings of all specimens you examine. Use a note-book of unruled paper (not too thin), if you write your notes in the same book, keep notes and sketches on separate pages, make your sketches large (natural size or, in most cases, enlarged) and clear (no shading, no superfluous or meaningless marks or lines, and no "inking-in" afterwards) Measure the specimens you are going to draw, record the measurements, and if enlargement is necessary in order to show details clearly, draw to a definite scale and note how many times your sketch is magnified (× 2, × 3, etc.) All the parts shown should be labelled; do not write the names inside the drawing, but at the end of a line drawn to the part named. Do not leave your sketches like nameless islands; write below each drawing the name of the plant, the part of the plant, the aspect represented, etc.

4. Hints on Lens Work.—So much can be done with a lens, especially if a microscope is not available, that some hints on lens work may be useful. The best kind of lens is the "aplanatic" or "platyscopic," which gives a flat field of vision without distortion of the edges; but a cheap triple folding-lens will do. It is easy to make a simple stand to carry the lens, and to allow of both hands being used in dissecting the specimen examined The lens can be fixed to a cork which slides up and down a vertical rod, *e g* a knitting-needle or hat-pin, inserted into a wooden base. Another useful plan is to get a piece of thick glass, about 9 by 4 ins ; to one side of it paste two pieces of thick paper, each 3 by 4 ins , one black, the other white (or a single piece, 6 by 4 ins , with one half painted black) Keep the papered side downwards, placing on the upper side the objects to be examined with the lens; move them along so as to see their appearance against the opaque white and black surfaces, and also against the light through the clear part of the plate See Ch IV.

5. The Parts of the Plant.—If we examine a number of common Seed Plants, we find that in most cases it is easy to recognise two sharply distinguished parts—the **root,** which grows downwards into the soil, and the **shoot,** which grows upwards into the air We shall at first confine our attention to a few plants whose shoot is erect (not burrowing in the soil, or creeping, or climbing) and herbaceous (not hard and woody), and find out in what respects these plants agree

6. *Materials for Study.*—Pull up, or dig up, specimens of all the following common plants · Broad Bean, Wallflower, Chickweed, Groundsel, White and Red Dead-Nettles.

Examine each plant thoroughly, after washing off any soil that may cling to the root, making notes and sketches of your observations The Broad Bean is given fully in this chapter as a type, and the other plants should be carefully compared with it at every point.

7. The Broad Bean Plant.—A good way in which to begin work on plant-life is to raise plants from seed The chief reason why the Broad Bean has been chosen for our first studies is that its seeds are easily germinated at any time of year, yielding in a short time vigorous young plants which serve admirably for practical work on plant-structure and plant-physiology Flowering and fruiting plants can be obtained throughout the summer months; in winter one must, of course, use seedlings raised indoors.

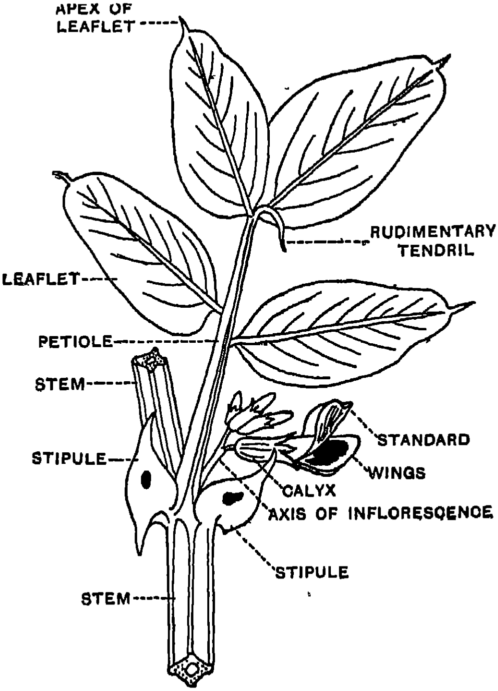

Fig. 1.—Part of a Broad Bean Plant

The Broad Bean (*Vicia faba*) is distinguished from other "Bean-plants" (French or Kidney Bean, Scarlet Runner) by its erect mode of growth, its square stem, its leaves with large stipules and from four to seven oval leaflets, its white flowers with a black blotch on each lateral petal (Fig. 1). It is commonly cultivated for its large edible seeds, and (like most cultivated plants) shows several varieties (Longpod, Mazagan, etc), differing in such details as shape and size of pod and seed and in times of flowering A common and distinct variety is the Field or Horse Bean, of which the seeds are used chiefly for feeding horses, the "straw" for stabling purposes, its seeds are much smaller and less flattened than those of the typical Windsor Broad Bean.

8 Dig up an entire Broad Bean plant in the garden (or the very similar Horse Bean grown in the fields), and free the root from the soil that clings to it by shaking it to and fro in a pailful of water and afterwards washing under a stream of water from a tap Set the plant in a basin of clean water, so as to allow the branching root to spread out, as well as to prevent its drying up

If complete flowering and fruiting Broad Bean plants cannot be obtained at once, begin by studying the seed and its germination (Art. 33 and rest of this chapter , Ch III). Make successive sowings in the garden,[1] also in pots and boxes, so as to get abundant material, in the form of seedlings, to start work with.

9. The Root consists of a main downward-growing axis (continuous with the upward-growing axis or stem), from which arise branches that spread out from it Are these first branches horizontal or not? Do they all make the same angle with the main root ? These first branches give rise in their turn to finer branches, in what directions do *these* grow in the soil, and how many times may the process of branching be repeated? Compare the different directions of growth taken by the main axis and by the successive sets of branches. How do these differences help the root to come into contact with as much soil-space as possible in the most economical way?

10. Arrangement of Rootlets.—Are the first branches scattered over the surface of the main root? To make out their arrangement, cut out a straight piece of main root, about 6 ins long, cut off the branches about an inch from their origin, and look along the piece from end to end. Sketch the piece, showing the rows of branches arranged along the axis[1] How many rows are there? Does the arrangement in longitudinal rows extend to the further branchings of the root?

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[1] Messrs Toogood and Son, Southampton, will send post free for 1s. two excellent gardening books—*Culture of Vegetables* and *Culture of Flowers.*

11. Origin of Rootlets.—Examine closely the place where a branch (rootlet) leaves the parent-root Is the surface smooth and continuous, or is there anything visible that suggests the way in which the branch arose from the parent-root? What further information is gained by cutting across the parent-root at this point with a sharp knife or a razor, and examining with a lens the cut surface? In what region of the main root are the branches shortest and thinnest? Look for young branches just emerging from the parent-root, in what direction do they grow at first?

12. Root-Tip.—Note the gradual tapering of the axis and of the rootlets towards their free ends, and the softness and whiteness of the latter as compared with the older parts Cut off the ends of some of the rootlets, about an inch behind the extreme tip, place them in a drop of water on a glass slide, and examine them with the lens; try holding the slide (1) against the light, (2) over a white surface, (3) over a black surface

13. Root-Hairs—Look for very fine threads, which will be found behind the root-tip, if the latter has not been damaged Those are the root-hairs, to which small particles of soil may still be sticking Root-hairs are more easily seen in seedlings They previously existed on the older parts of the root, but they disappear as the root grows, while new hairs are continually being formed just behind the growing extremity of the rootlet.

14 Root-Cap.—At the end of each rootlet, note the more transparent conical mass at the extreme tip, separated from the denser main body of the rootlet by a curved outline. This conical mass is the root-cap, it is thickest at the tip and extends a little distance at the sides, fitting over the end of the rootlet like a thimble on a finger

Root-hairs and root-cap can be more easily examined in a seedling, these structures are often damaged in removing the mature plant from the soil.

15. Root-Nodules.—Note, here and there on the main root and the rootlets, little wart-like swellings, varying in size and shape. These swellings (nodules or tubercles) are characteristic of the roots of Beans, Peas, Clover, and allied plants.

---

[1] This arrangement can easily be made out in seedlings. In the Broad Bean the side-roots are usually in 5 rows on the main root; in the Scarlet Runner and the French Bean there are usually 4 rows, arranged with great regularity on the main root.

16. Hard and Soft Tissues of Root.—Cut the main root and the branches at several points, transversely and longitudinally, and note the hard central part surrounded by the soft outer tissue. Scrape the latter off, all round a piece of root, to see the hard central cylinder. Is the hardness of this central tissue due to the presence of woody substance, as in old roots as well as stems of trees? It is easy to find out. Get some aniline chloride (about 1½d. per ounce), dissolve in a little alcohol, and add water to make a 10 per cent. solution. Dip a wooden match into the solution; does the match turn bright yellow when withdrawn? If the colour does not appear quickly, add a few drops of hydrochloric acid to the solution. This solution affords a ready test for woody substance (*lignin*). Place some on your sections of the root, and notice which parts turn yellow.

17. The Shoot.—The whole of the upper part of the bean-plant, above the ground, may be called the *shoot*, as distinguished from the root, which grows in the soil. In passing from the downward-growing axis or root to the upward-growing axis or stem, what changes do you notice in (*a*) shape of axis, (*b*) colour of axis, (*c*) nature of appendages carried by the axis? Note the four flat sides of the stem, and its green colour, often tinged with red. We saw that the root consists of a main cylindrical axis which is covered at the tip by a root-cap and which bears as appendages (*a*) root-hairs, (*b*) root-nodules, (*c*) rootlets which repeat the form of the main axis and bear the same appendages. What are the appendages of the shoot-axis (stem)? (*a*) Some of these consist of a stalk which is grooved on its upper surface, carries a number of thin flat outgrowths on either side, and (usually) ends in a slender prolongation. (*b*) Other appendages of the stem consist of a four-sided stalk which carries appendages like (*a*), and which therefore repeats the form of the main stem itself and may be called a *branch* of the stem, just as a rootlet is a branch of the root. In many plants, *e.g.* Wallflower, the first kind of stem-appendage consists of an undivided thin flat piece; such an appendage is called a *simple leaf*. The corresponding appendage of the Bean is also a leaf, but here the leaf is *compound*, its thin flat portion being divided into several pieces, the *leaflets*.

18. Air-Spaces in Shoot.—You have noticed a central cavity in some of the cross-sections. How far does this cavity extend in the stem, and is it continuous? Find out by slitting up the whole stem from top to bottom Does it run out into the branches and the leaves? What does it contain in the uninjured living stem? Lay a whole plant in a basin, cover it with cold water, and cut across the stem and the branches at several places: what do you notice escaping from the cut ends? Is this central cavity the only part that contains air? Take the plant out, replace the cold water by hot water (just boiled), and notice what happens when you place in it (*a*) a piece of stem only, with the cut ends previously well plugged with plasticine, (*b*) a whole plant

The results of these simple experiments show that the whole shoot contains air-spaces and that these communicate with the atmosphere by openings scattered over the surface. From the number of bubbles seen to escape, the leaves evidently have more air-openings than the stem Which side of a leaflet, upper or lower, seems to have most openings? These air-openings are called *stomates.*

19. Hard and Soft Tissues of Stem.—Cut slices across the stem at several places, starting with the uppermost (youngest) parts and working downwards. Arrange the slices in order on your glass plate, cover with a little water, and examine with the lens Note that the young parts are solid and soft, while the older parts are hollow and hard. Note the hard tissue lying within the soft green outer tissue. In young parts the hard tissue consists of separate strings (bundles) forming a ring of whitish points in cross-section; note the extra bundles lying outside of the ring, occupying two of the four projecting corners (there is a small bundle in each of the corners alternating with these two, but they are harder to see) In older parts the bundles are joined in a continuous hollow cylinder or tube (a complete ring in cross-section), but the extra bundles lie outside of this in the same positions as in the young parts.

Now run the water off and place on the sections a little aniline chloride, noting the result. Cut the stem longitudinally into strips and note the bundles, which will be easier to follow if the strips are placed in potash solution for a short time Scrape the soft outer tissue from a piece of stem and notice the hardness of the bundles, especially in the older parts.

20. The Leaf.—Each leaf consists of an axis (leaf-stalk) which bears right and left a number of thin flat outgrowths The two lowest of these lie on each side at the base of the leaf-stalk, close to the stem; they are called *stipules,* to distinguish them from the leaflets carried higher up on the stalk The leaflets are rather variable in number, but we usually find a pair close together, right and left, near the top of the stalk, and from two to four spaced out on the stalk below these. Note the difference in shape between the leaflets (oval) and the stipules (triangular, like one lateral half of a spear-head), what other differences do they show? Notice the slender outgrowth into which the leaf-stalk is (usually) prolonged above the leaflets (Fig 1).

Do any of the leaves in your plants bear a leaflet in place of this outgrowth, and do you find any leaves ending in structures intermediate between these two extremes? Note that the leaf-stalk comes off at one of the ridges of the stem, the stipules being against the two adjacent flat sides of the stem.

21. Arrangement of Leaves.—Follow the ridges along the stem, and find out in how many rows the leaves are arranged. Do leaves come off at all four ridges? Do the ridges run straight up and down the stem, or is there any twisting? Compare the leaf-arrangement in the Broad Bean with that observed in other plants which have square stems—*e g* White or Red Dead-nettle, Mint, Figwort, Coleus—and note any differences.

22. The Leaflet.—Notice the chief vein (midrib), which runs through the leaflet from the base to the tip. What do you notice at the tip? Note the branch-veins arising on each side from the midrib, the finer veins arising from these, and the delicate net-like arrangement of the still finer veins (hold the leaflet against the light). What differences do you notice between the upper and lower surfaces of the leaflet? Notice that the chief veins appear as grooves on one surface (which?) and as projections on the other.

Hold the leaflet, with the lower surface towards you, between the thumb and forefinger of each hand, and, starting from a point on one edge, tear the leaflet across. Notice the thin colourless skin which can be torn off in this way, and the green inner tissue which is exposed; small specks of the green tissue remain attached to the skin, unless the tearing is done very carefully (try it several times, starting at different points on the edge of the leaflet). Now try to tear off the upper skin in the same way, and notice that it also is colourless, though a good deal of the green tissue always comes away with it. The leaflet therefore consists of a thin colourless skin covering its upper and lower surfaces, and a thick middle green tissue which is denser towards the upper surface and looser towards the lower surface (how is this inferred from your tearing experiments?) and which contains the veins.

23. "Bloom" on Leaf-surface.—Dip a leaflet into water and notice, on lifting it out, that the water runs off the surface very quickly, leaving it dry. Lay a leaflet on the table and place a drop of water on either surface in turn: notice in both cases that the water forms a globule instead of spreading over the surface. This shows that the leaf is not easily wetted by water, and suggests that the surface is covered by some substance like wax This waxy substance is similar to that which forms the "bloom" on Grapes, Plums, etc, so that one might say the Broad Bean leaflet is covered with "bloom," which prevents water from wetting it and reaching the inner tissue Try to remove the bloom by rubbing the leaflet gently (1) with a dry cloth, (2) with a cloth dipped into warm water, water placed on the leaflet will then wet the surface and spread over it

24 The Stipules—How does a stipule differ from a leaflet in shape, colour, and texture? Has it any veins (hold it against the light)? Notice the patch near the centre of the stipule, at first it is bright red or violet in colour, later it becomes brown or black On which surface of the stipule is this patch most easily seen? This patch consists of minute glandular hairs, very closely crowded together on the lower surface of the stipule. A similar patch of glands occurs on the stipule in the Common Vetch of fields (*Vicia sativa*), the nearest ally of the Broad Bean among British plants, its functions are doubtful.

25. The Leaf-Stalk (Petiole).—Note the groove on the upper surface, making the leaf-stalk gutter-shaped What does this comparison with a gutter suggest as to the use of the groove in wet weather? Test the matter by a simple experiment with a watering-pot, or watch a plant during a shower of rain Does this suggest also the use of the little pointed tip at the end of each leaflet? What about the narrow prolonged tip at the end of the leaf-stalk?

The nearest relatives of the Broad Bean are the Vetches and Peas, which differ from our type in being weak-stemmed climbing plants Get any of these (*e g* Sweet Peas) and compare their leaves with that of the Broad Bean What light does the comparison throw on the nature of this part of the Broad Bean leaf? A special organ used for climbing is called a *tendril* Make out with the lens the structure of the leaf-stalk. How are the bundles arranged? Is there a central air-channel, and is it continuous with the air-channel of the stem, or the branch, that bears the leaf?

26. Branches and Buds.—You will have noticed that each branch of the stem arises just above the base of a leaf, and that as a rule they become shorter towards the upper end of the stem Pull off the young leaves at the end of the stem or of a branch, to see the small young branches (*buds*), one above the base of each leaf These buds are called *axillary*, the space between the leaf-base and the part of the stem above it being called the *axil* of the leaf At the very end of the main stem and of each branch there is a *terminal bud* A bud is simply a young shoot, consisting of a short axis (stem) bearing young leaves which are closely crowded together and overlap the growing apex of the axis. Later on, the stem part of the bud grows in length and the leaves become spaced out on it, as well as growing larger.

The points on the stem where leaves come off are called *nodes*, the parts between the nodes being called *internodes*, but these names, though useful in describing plants, are often associated with a false conception of the shoot as being made up of "joints," each consisting of an internode and a node bearing one or more leaves The node is merely a place where a leaf stands on the stem, and where the bundles of the stem divide and join with those of the leaf and also with each other, causing a swelling

27. The Flowers[1] of the Broad Bean are arranged in small clusters, each cluster arising in the axil of a leaf, and each flower is attached by a short stalk to the axis of the cluster, which occupies the same position on the shoot as an ordinary branch The cluster or flower-bearing branch is called an inflorescence Turn down or pull off the leaf just below an *inflorescence*, and examine the latter closely. This special kind of inflorescence, with the individual flowers stalked and spaced out on the axis, is called a *raceme*, the youngest flowers are nearest the top.

Note the parts of a single flower (Figs. 2, 3), starting from the outside .—

28.[2] **The Calyx**, a greenish or colourless cup, with its free edge produced into five pointed lobes. Note the veins which start from the bottom of the cup, one running up the middle of each lobe, others between the lobes

29. The Corolla (Fig. 2), consisting apparently of four pieces, a large upper piece (*standard*), two smaller side pieces (*wings*), and a lower boat-shaped piece (*keel*) Note the way in which the standard is folded below over the wings, which in turn enfold the keel The standard is on the upper (posterior) side of the flower, *i e* the side towards the axis of the inflorescence ; note the position of each of the calyx-lobes with reference to the axis, the odd one being the lowest.

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[1] If Broad Bean flowers are not available, use those of Sweet Pea, or Gorse, or some other plant of the Bean Family

[2] In dissecting flowers use a sharp penknife (a pair of fine scissors will also be useful), a pair of forceps for seizing the parts of the flower, and a lens

Open the calyx by cutting or tearing it between the two upper lobes, to see the exact shape and position of each of the four parts of the corolla. Remove the standard and sketch it (front surface and side view), note its broad upper part, marked by coloured streaks, and the narrow lower part by which it is attached to the *receptacle* (*i e* the expanded upper end of the flower-stalk, to which all the parts of the flowers are attached). In each wing note the narrow stalk, and the broad oval portion which has a large blackish spot Gently pull each wing outwards, and note that it clings to the outer surface of the keel can it be pulled off without tearing anything? Note the way in which the wing on each side is locked with the keel, at this place the wing and the keel show a series of folds, the corrugated surfaces fitting together

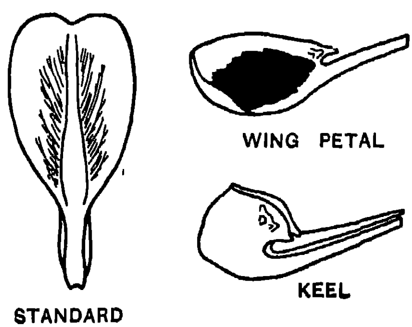

Fig 2.—Corolla of Broad Bean

Remove and sketch one of the wings, both from the inner side and the outer side In removing the standard and the wings, note that these pieces (*petals*) alternate in position with the calyx-lobes, *i e.* the insertion of each of these three petals is just inside the space between two of the calyx-lobes. Now examine the keel, and note that it is carried on two separate stalks; detach these at their bases and pull them apart, when the keel will split along its sharp lower edge into two pieces. The corolla, then, consists in reality of five petals, the two lowest being attached to each other to form the keel, and the five petals alternate in position with the five *sepals* (calyx-lobes).

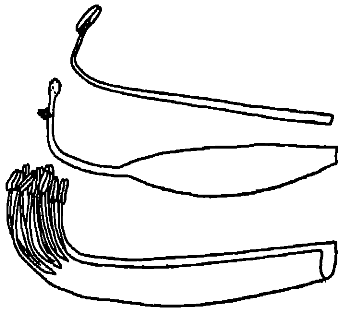

Fig 3 —Stamens and Pistil of Broad Bean

30. The Stamens (Fig 3).—On opening up the keel you will see a number of small oval bodies (*anthers*), each carried at the end of a thin stalk (*filament*) How many anthers are there? If you see any stalks bare at the end, try another flower (a young unopened flower is best). Trace the stalks down, and notice that most of them are joined below to a thin colourless plate which is folded longitudinally Does this folded plate form a complete tube or is it open? Where is the opening, and how is it covered over? Are any of the filaments free from the folded plate? Each anther, with its filament, constitutes a *stamen*, but only the uppermost stamen is free right down to the flower-axis; the others arise from the "stamen-trough" The upper parts of all the stamens bend sharply upwards, to suit the shape of the keel, in which they are enclosed, there is a narrow opening along the upper side of the keel, above the free stamen.

Examine an anther with the lens, noting the two lobes divided by a longitudinal groove, and each showing a less marked groove; the anther consists of four *pollen-sacs* lying side by side. This can only be seen in a young flower; in an older one the anther will have opened by two slits, one at each side, allowing the yellow dust-like *pollen* to escape Sketch the ten stamens, with the "stamen-trough" as seen from the side, then cut round the base of the trough, remove it, and sketch it spread out.

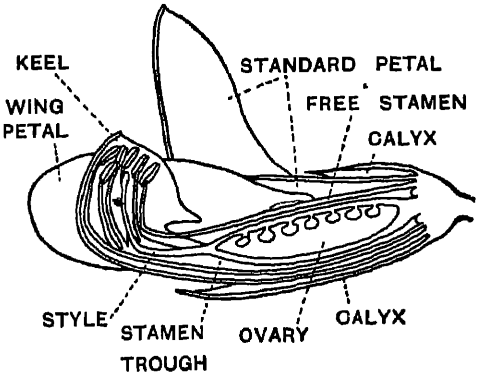

Fig 4.—Longitudinal Section of Broad Bean Flower.

31. The Pistil (Fig 3), the innermost part of the flower, is now seen. It consists of a long green lower part with flattened sides, and a tapering free end produced into a slender outgrowth (*style*), which bends upwards and bears a tuft of hairs on the lower side of the bend, just below the tip. Examine these parts carefully, and sketch the whole pistil in side view The lower part of the pistil resembles a small bean-pod, and for the present we may call it the "young pod" Is it hollow, and does it contain anything answering to the seeds found in the bean-pod? Cut it across, and open it up, to see what we may at present call the "young seeds." To which side (upper or lower) of the cavity are they attached?

Make and sketch a longitudinal section of the entire flower corresponding to that shown in Fig 4.

32. The Fruit.—You should watch some flowers from day to day, or compare different flowers on the same plant, and note any changes that occur as they grow older. What becomes of the calyx, corolla, stamens, style, young pod? What parts of the flower (*a*) wither, (*b*) persist, (*c*) grow larger? Watch the growth of the fruit (pod), opening up pods of different ages, to see what changes have occurred. How does the pod change in texture and in colour as it grows older and larger? How does the ripe pod open to let the ripe seeds out?

Do any changes occur in the rest of the plant (leaves, etc) while the pods are ripening? What happens if you leave the plant undisturbed in the ground after the pods have ripened? What parts of the fruiting Bean-plant remain alive during the winter? What will next year's plants be produced from?

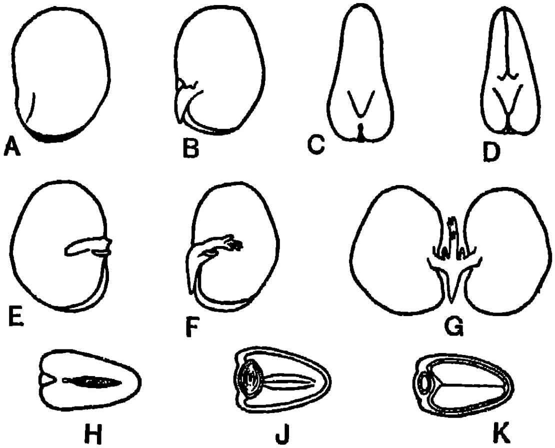

Fig 5 —Seed of Broad Bean. A, C, and H are views of the entire seed, B, D, E, F, and G are views of the embryo (seed-coat removed), J and K, seed cut across (in J the cotyledons and radicle are removed, to show the radicle-pocket)

33. The Seed.—Examine some pods containing seeds, also get a supply of dry seeds (Windsor Broad Bean, about 6d per quart) Notice the black (or brown) mark on the thicker end of the seed (Fig 5) How was this mark on the loose seed produced? How does the seed become loose, and what does it break from when the pod opens? This mark may be called the *scar* of the *seed-stalk*. The dry seeds have a shrunken appearance, while fresh seeds are smooth and rounded. In what other respects do dry seeds differ from fresh seeds?

Put the dry seeds into water, and notice that in a few days they have swelled and become smooth and rounded, like the fresh seeds. Fill a wooden box, at least a foot deep, with moist sawdust, bog moss, or soil, and plant seeds about half an inch below the surface. See Chapter III for details of germination. In the young green shoot that comes above the soil notice the forms of the earliest leaves.

34. Seed-coat.—Examine from time to time some dry seeds which have been placed in water, and notice that at first the surface becomes thrown into folds. Cut across the seed, and note that these folds are produced by a *coat* which encloses the contents of the seed. Evidently the coat at first absorbs water and swells more rapidly than the contents; this loosens the coat and makes it much easier to remove in a seed that has been soaked in water for a day or two. The wrinkling of the seed-coat is very marked in the French Bean and the Scarlet Runner.

35. Micropyle.—How does the water enter the seed? Is there any opening in the coat? The folds seen in the soaking seed usually appear first around the *edge* of the seed; this suggests that the water enters somewhere on the edge. Do you recall how we found out that various parts of the bean-plant contained air, which communicates with the atmosphere by openings on the surface of stem and leaves? Perhaps the seed as it lost water took in air, as a piece of wood does in drying. Drop some dry seeds into water that has just been boiled, and notice the stream of bubbles given off. Where do the air-bubbles escape? Wipe this end of the seed dry, in some seeds that have soaked for a few days, and look for the opening; squeeze the seed and see whether water oozes out. This opening is the *micropyle* (Greek, "little gate").

36. Seed-lobes, etc.—Remove the coat from a soaked seed, starting at the end opposite the scar. Note the two large whitish *seed-lobes* or *cotyledons*, whose flat or slightly concave inner sides are pressed against each other. When you have stripped off the upper part of the coat, pull off the rest of it (the part covering the scar end) entire, like a cup. Note the smooth tapering body projecting from between the cotyledons and pointing towards the end of the scar where the micropyle is; also note the little pocket on the inner surface of the seed-coat, into which the projecting body fits.

Now pull apart the seed-lobes, and remove one by breaking across the short stalk by which it is joined to the thickest part of the projecting body This brings to view a curved body lying between the seed-lobes, fitting into a groove on the flat inner surface of each lobe, and forming a continuous line with the projecting body Has it, like the latter, an even surface, or does it bear any outgrowths? Examine it carefully with the lens, and try to turn back the outgrowths with a pin, without tearing them, so as to make out the positions of the outer ones.

37. The Seedling (Figs 5, 6).—The first leaf above ground consists of a single piece with its margin cut by shallow notches into three lobes, the second leaf is divided deeply into three lobes, the middle lobe long and narrow, the lateral lobes broad and triangular. Then come several leaves, each consisting of two stipules and a short stalk which bears a pair of oval leaflets (note their folded appearance at first) and is prolonged into a rudimentary tendril. After several leaves like this we get leaves of the mature type, in which the stalk is lengthened below the terminal pair of leaflets, and carries two, three, or four additional leaflets Have these early leaves, like the later ones, buds in their axils? In the first two leaves that appear on the young stem the three lobes evidently represent the two stipules and the rudimentary tendril (or the end leaflet which sometimes replaces it).

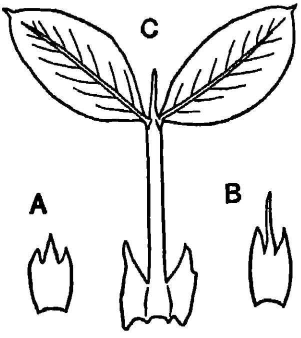

Fig 6 —Earliest foliage-leaves of Broad Bean seedling.

38. Seedling compared with Seed.—Carefully pull up a seedling without injuring the root, and compare the latter with the root of the mature plant. Trace the young root upwards and the young shoot downwards, and notice the torn seed-coat and the cotyledons. In the axil of each cotyledon there is usually a bud. The cotyledons are therefore *leaves*, though differing from ordinary leaves (foliage-leaves) in many respects. They are often called the "seed-leaves."

The young plant, or seedling, has evidently grown from the whole of the seed-contents (*i e* everything inside the seed-coat), for we have seen that even the cotyledons are leaves, having buds in their axils The cotyledons are the first leaves of the young plant, which is called the *embryo* while still inside the seed The embryo consists of an axis which bears the two cotyledons at about the middle, and which ends in a root[1] (covered by a root-cap) at one extremity and a bud[2] (bearing young foliage-leaves) at the other.

39. Seedling compared with Mature Plant.—We have noted the simple form of the earliest leaves as compared with the older ones. The cotyledons are opposite each other and are attached to the same point on the axis, but the early foliage-leaves show the same arrangement (alternate, in two opposite rows) as in the mature plant The root of the seedling shows the same general appearance and structure as that of the mature plant, into which it grows, later on forming the characteristic nodules

If you were unable to get mature Broad Bean plants when you began work, you will find it very easy to raise the plants from seed in pots of soil indoors or in the garden Some plants should also be raised in "culture solution"

QUESTIONS ON CHAPTER I

1. For what purposes is the Broad Bean grown (*a*) by the market-gardener, or in kitchen-gardens, (*b*) by the farmer in his fields?

2 At what times of year is the Broad Bean commonly sown, and during what months may it be seen (*a*) in flower, (*b*) with ripe fruits?

3 How are the lateral roots arranged on the main root in the Broad Bean, and in what directions do they grow?

4 Write down in two parallel columns the contrasted characters of Root and Shoot, as to direction of growth, colour, shape of main axis and branches, appendages carried on axis, etc.

5 Describe the naked-eye features of the main axis (stem), the branches, and the leaves How are the leaves arranged, and how are they related to the branches?

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[1] The root of the embryo is termed the **radicle.**

[2] The shoot-bud of the embryo is called the **plumule.**

6 Describe the internal structure of the stem, as seen in sections examined with a lens

7. Describe the general appearance of a leaf of Broad Bean Sketch a single leaf, with the part of the stem or branch from which it springs.

8. Describe the arrangement of the hard tissue of root, stem, leaf-stalk, and leaflet. Try to account for the differences you describe

9 Describe exactly what happens when you pour water on the leaves of a Broad Bean plant.

10 Describe the leaves of any other plants belonging to the Bean family which you have examined, and compare them with those of the Broad Bean, noting the points of resemblance and difference.

11 Describe the naked-eye appearance of the various parts of the Broad Bean flower, with sketches

12. Describe, from your own observations, what insects may be seen on the Broad Bean plant or visiting its flowers Which of these insects do you suppose are injurious, and which useful, to the plant?

13. Describe, from your own observations, the changes that occur in the flower from the time it opens until the fruit (pod) is ripe.

14 How does the pod open if allowed to remain on the plant until it is quite ripe, and what do you find inside it?

15 Describe the external features of a Broad Bean seed, with sketches.

16. Describe the parts seen after removing the seed-coat, with sketches

17 Describe what happens when a dry Bean seed is placed in water, and what you see after planting the soaked seed in soil or sawdust

18. Describe a young plant (seedling) of Broad Bean, and compare its parts with those seen in the seed

19 How do the earliest leaves of the seedling differ from those of the mature Broad Bean plant?

CHAPTER II.

AIR, WATER, AND SOIL

40. The Plant's Surroundings.—In order to understand the physiology of plants it is absolutely essential to have a good working knowledge of the various factors which make up its surroundings—the chemical and physical properties of air, water, and soil We must also know something about heat and light, which are of vital importance in plant-life

This chapter should be referred to again and again during your work on plant physiology and ecology. Do not stop now to read through this chapter, go on with your work on seedlings and the rest of this book, coming back and reading this chapter bit by bit as your practical work on plants progresses, also using it for reference.

41. Hints on Fitting up Apparatus.—As you will be constantly called upon during the course to accurately fit flasks, etc, with corks bored with one or more holes, and bend glass tubing to various angles, you had better master these simple operations at once

(*a*) **Fit a Flask of Medium Size with a Cork.**—Select a cork a little too large, wrap it in a piece of paper, and using gentle pressure with your foot, roll it to and fro upon the ground This softens the cork, and the risk of breaking the neck of the flask is lessened. If still too large, file down the cork equally all round

(*b*) **Bore a Cork Lengthwise and Fit a Glass Tube tightly into the Hole made.**—Select a cork-borer (Fig 8) slightly less in diameter than that of the tube to be fitted into the cork [1] Place the cork against the edge of your bench, as shown in Fig 7. Press the borer gently into the narrower end of the cork and work it alternately round to right and left The borer must be sharp to make a clean cut, and the tube must fit tightly.

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[1] The cork-borer is a brass tube about 5 ins long sharpened at one end. At the other are two small holes opposite each other, through these the accompanying iron rod may be thrust to serve as a handle. The borers are generally put up in sets of three or more.

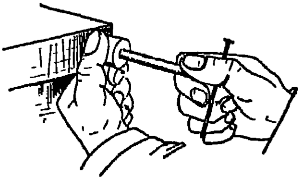

Fig 7.

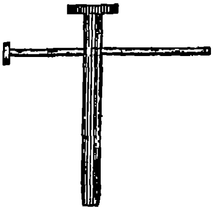

Fig 8

Now take the cork prepared in (*a*) and bore two parallel holes in it similar in position to those in the wash-bottle (Fig. 11)

(*c*) **Cut some Glass Tubing about ¼ in. in Diameter into Lengths 4 to 6 inches.**—Lay the tube flat on the bench and with a sharp triangular file make a scratch across it where required, the pressure used being regulated by the thickness of the tube Now hold the tube in both hands, with the scratch away from the body and the tips of the thumbs touching each other just opposite the scratch Break the tube by bending it as you would a thin stick, giving a pull at the same time Round off the sharp ends by fusing them in the Bunsen flame.

(*d*) **Bend some pieces of Glass Tubing to form Right Angles.**—Use an ordinary spreading gas flame lowered until it is about 2 ins. across Place the tube over the flame for a few seconds, and gradually bring it down into the hottest part, as shown in Fig 9 Turn the tube round and round till it softens, then allow one end to fall until it makes the required angle The bend should be round and smooth, without buckling; the Bunsen flame is apt to give buckled bends (Fig 10).

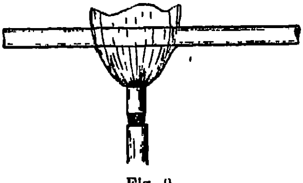

Fig 9

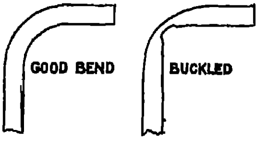

Fig 10

(*e*) **Bend some Tubing twice at Right Angles so as to form Three Sides of a Rectangle.**—When laid down all three sides must touch the bench

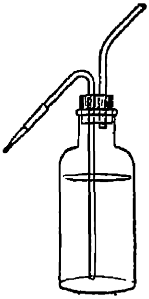

Fig 11.

(*f*) **Make two Nozzles.**—Hold a piece of tubing by both ends, soften the middle, and pull the ends slightly apart. Cut the tube through and round off the ends.

(*g*) **Complete the Wash-bottle.**—Bend suitable pieces of tubing to form angles equal to those seen in the wash-bottle in Fig 11. Push them through the cork prepared in (*b*), and attach a nozzle by means of an inch or so of rubber tube.

42. Experiments.—In making experiments, sketch the apparatus used Make notes of the materials experimented with (name of plant or part of plant, number, condition, stage of growth, etc); the duration of the experiment, date, time of day, the external conditions (temperature, light-intensity, humidity, barometer-reading, etc.), the precautions which seem necessary and the sources of error which may spoil the results

Always make "control" or "check" experiments, using the same form of apparatus, set up at the same time, but with one or other of the conditions different, *e g* in darkness instead of light, with the plants omitted; with killed instead of living plants, with plants in different stages of growth Also make "repeat" experiments, using different plants under similar conditions or the same plants at different times of year or day, etc.

If your experiments do not succeed, try again; if they give discordant results, try to account for these and to think out a method for a repeat experiment under different conditions, with special precautions, or for making a new experiment altogether In drawing conclusions, always try to distinguish between probability and actual proof.

43. Balances and Weights.—For various experiments with plants you will need (1) a rough balance for large weights, and (2) a finer balance for smaller weights. For the first, cooking-scales with weights from 7 lbs to ¼ oz., or a cheap spring-balance, will suffice If you have not a small balance, get a cheap pair of apothecaries' scales (about 4s) and suspend them from a ⅂-shaped wooden frame fixed to a board below If you get a single gramme-weight and the fractions, you can make duplicate gramme-weights from sheet-lead

The **metric system** of weights should be used The unit of length in this system is the metre, a platinum rod kept in Paris and originally supposed to be a tenth-millionth part of the distance from the North Pole to the Equator The metre is multiplied and divided by 10 for the higher and lower measures of length, the Greek prefixes *deca-*, *hecto-*, and *kilo-* represent 10, 100, and 1000, and the Latin prefixes *deci-*, *centi-*, and *milli-* represent 1, 01, and ·001. The same prefixes are used in the other measures The unit of volume is the cubic decimetre, or **litre,** but the cubic centimetre (*i e* the millilitre), usually written "c c.," is often used for volumes less than a litre (1000 c.cs) The weight of 1 c c of distilled water at 4° C is the unit of weight, the **gramme,** with multiples and subdivisions as before

Place an inch-rule graduated to tenths or eighths and a centimetre-rule graduated to millimetres edge to edge, and find how many centimetres are equal to a foot. If the scales are accurate, you should get the number 30 5.

Metric Equivalents (Approximate).

1 inch = 2·5 centimetres.
1 ounce (avoir) = 28 grammes.
1 fluid ounce = 28 c cs.

1 centimetre = $\frac{2}{5}$ inch.
1 gramme = 15 grains.
100 c.cs. = $3\frac{1}{2}$ fluid ounces.

44. Thermometers.—An instrument for measuring temperature is called a thermometer, and the one in most general use is the Mercury Thermometer. This consists of a glass bulb containing mercury, and a tube of very fine bore which is joined to the bulb and sealed off at the top. All liquids expand when heated (as also do ordinary solids and gases), so that a rise of temperature causes the mercury to expand in the bulb and hence to rise in the capillary tube The narrower the bore of the tube, the greater will be the rise of the mercury in it, and in this way the expansion of the mercury, which is really very slight in amount, is made readily visible.

If the bulb is placed in melting ice the point to which the mercury sinks in the tube is marked freezing-point, 0° Centigrade or 32° Fahrenheit. On placing the instrument in steam at atmospheric pressure, the boiling-point of water is indicated, and is marked 100° Centigrade or 212° Fahrenheit The tube is marked off into degrees between these two points, the freezing- and boiling-point of water On the Centigrade scale there will be 100 divisions between the two, and on the Fahrenheit scale 180

Mercury freezes at −39° C and boils at 357° C , so that it cannot be used for temperatures above and below these limits The freezing-point of alcohol is lower than that of mercury, and hence it can be used for still lower temperatures , but since alcohol boils at 78° C it cannot be used for temperatures at all approaching that of boiling water

45 Maximum and Minimum Thermometers.—It is often necessary to know the highest or lowest temperature reached in a given interval of time For instance, it is usual in making meteorological observations to record the highest (maximum) temperature attained during the day, and the lowest (minimum) temperature reached during the night. For these purposes maximum and minimum thermometers are employed

Six's maximum and minimum thermometer is one of the oldest of its class, and is at once a maximum and a minimum thermometer. Its general plan of construction is shown in Fig 12 The bulb B and part of the stem down to *m* are filled with alcohol This is the real thermometric part of the instrument; the column of mercury, *m m'*, which occupies the U-shaped part of the tube, merely acts as an index The tube above *m'* and the lower part of the bulb C are filled with alcohol, the upper part of C contains only alcohol vapour, so as to allow for expansion

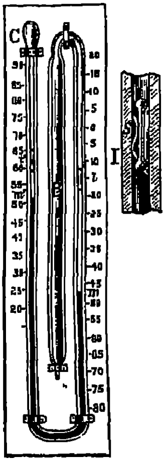

Fig 12

As the alcohol in B expands or contracts, the extremities, *m* and *m'*, of the mercury column rise or fall as the case may be, and the extreme point reached in each case is indicated by one end of a light steel index, *i* or *i'* (shown on a larger scale at I) This index, is pushed before the mercury column, and is prevented from returning by means of a spring, *s*, which is just strong enough to hold it in its place The position of the index *i* evidently indicates the minimum temperature reached, and that of *i'* the maximum temperature When it is required to set the instrument ready for any observation, these indices are brought into contact with the ends *m* and *m'* of the mercurial column by means of a small magnet This instrument is largely used by gardeners and nurserymen

46 Black-Bulb Thermometer —This is an instrument used for measuring the amount of radiation from the sun that falls on a given spot (Fig 13) It consists of a thermometer whose bulb is coated with lamp-black This substance is used because practically all the

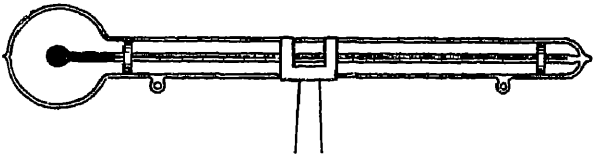

Fig. 13 —Black-bulb Thermometer

rays of sunlight that fall on it serve to raise its temperature; the latter, measured by the mercury, gives therefore a good indication of the intensity of the radiation As the lamp-black would readily part with some of its heat to the air, and the constant motion of the air would soon carry off a good deal of heat, the black-bulb thermometer is usually enclosed in a glass from which the air has been pumped

An ordinary thermometer, if placed in direct sunlight, would act in the same way but less perfectly. But what is usually wanted from a thermometer is the temperature of the *air* that is why thermometers are placed "in the shade," where they are not directly warmed by the sun's rays The fact that the temperature of the air, shown by an ordinary thermometer in the shade, is much less than that of the lamp-black shown by the black-bulb thermometer, is a striking illustration of the smallness of the heating effect of the solar rays on the air through which they travel In fact, the warmth of the air is chiefly produced by contact with the earth, not directly by the sun's rays, and in the higher regions of the atmosphere the air is very cold in the brightest sunshine.

47. Surface Tension.—The free surface of water (and other liquids) behaves much as though it were covered by an elastic membrane (surface film) It is this surface action that draws the raindrop into the form of a sphere as it falls through the air, and that causes water to form into spheres on a dusty floor or on the leaves of many plants The cause of surface tension is the attraction of the particles (molecules) of water for each other This attraction extends throughout the liquid, but only the molecules at the surface show its influence, because it is only these that are not pulled evenly in all directions by water-molecules on every side

48. Capillarity, Capillary Attraction—When open glass tubes, having a very small bore, are held vertically in a liquid, there is always a difference between the level of the liquid inside the tube and that of the liquid outside. If a glass tube of this kind be placed in water, the level of the water in the tube will be above that of the water outside, and the surface of the water in the tube will be concave In the case of mercury, the level inside will be below that outside, and the surface will be convex. The finer the tube, the more marked will the result be The liquid only ascends when it is capable of wetting the sides of the tube

Hence we have two kinds of capillary action—in one the liquid wets the tube, ascends, and has a concave surface, in the other it does not wet the tube, descends, and has a convex surface We need only deal with the capillary ascent of water, which is of importance in plant-life If the tube (supposed circular in cross section) is 1 in in diameter, the water rises 0 054 in ; if 0 1 in. diameter, the water rises 0 54 in , and so on In a tube 0 001 in diameter the water rises 54 ins

This capillary action is closely connected with the surface tension of the water, and it is therefore natural that the total lifting force which supports the column of water should be proportional to the circumference of the tube The circumferences of tubes increase in the same proportion as their diameters,[1] hence a tube 0 1 in diameter will lift above the water-level ten times as much water as a tube 0 01 in diameter. But the area of the water-column increases as the *squares* of the diameters of the tubes,[1] hence the wider tube will only lift its column one-tenth as high as the narrower one, its load being then ten times as great The following table shows the relation between the diameter of a cylindrical capillary tube, the volume of water raised, and the height of the water column·

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[1] Circumference of a circle = 3·14 × diameter

Diameter of tube	Volume of water raised	Height of water-column
1·0 in.	0·0429 cubic in	0·0546 in
0·1 ,,	0·00429 ,,	0·546 ,,
0·01 ,,	0·000429 ,,	5·46 ,,
0·001 ,,	0·0000429 ,,	54·6 ,,

Very fine tubes that show this phenomenon well are called *capillary* (*i e.* hair-like) *tubes*, and the phenomenon is known as *capillary* or capillary attraction and repulsion The "soaking up" of ink by blotting-paper is an example of capillary attraction, the fibres of the blotting-paper being really minute tubes, whose substance is "wetted" by the ink, so that the level of the liquid rises considerably in the tubes Other cases are the "sucking up" of water by a lump of sugar, the rising of the melted wax in the wick of a burning candle or of oil in a lamp-wick, and the diffusion of water through soil

49. Capillary Tubes.—Fix upright in coloured water a few clean glass tubes whose bores vary in diameter from an inch down to that of thermometer tubing It will be found that the water rises a little way up even the widest tube, whilst in the smallest it mounts an inch or more above the outside level The smaller the bore the higher the water rises.

50. Osmosis—When dry raisins are placed in water, they swell up just as dry seeds do On the other hand, if fresh grapes are placed in a strong solution of sugar, they shrink. The swelling of the dried seeds or raisins and the shrinking of the fresh grapes are due to *osmotic pressure*

If we place in a vessel of water a bladder filled with a strong solution of a substance having an "attraction" for water, *e g* sugar, a *large* amount of the water will diffuse (pass by osmosis) into the bladder (*endosmosis*), while a *small* amount of the solution will diffuse out (*exosmosis*) The weaker solution diffuses faster, and this continues until the same concentration is acquired, when it is equally rapid in both directions, and hence apparently ceases Meanwhile considerable pressure is set up inside the bladder, owing to rapid endosmosis.

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[1] Area of a circle = 785 × square of diameter

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0·01 ,,	0·000429 ,,	5·46 ,,
0·001 ,,	0·0000429 ,,	54·6 ,,

Very fine tubes that show this phenomenon well are called *capillary* (*i.e.* hair-like) *tubes*, and the phenomenon is known as *capillary* or capillary attraction and repulsion. The "soaking up" of ink by blotting-paper is an example of capillary attraction, the fibres of the blotting-paper being really minute tubes, whose substance is "wetted" by the ink, so that the level of the liquid rises considerably in the tubes. Other cases are the "sucking up" of water by a lump of sugar, the rising of the melted wax in the wick of a burning candle or of oil in a lamp-wick, and the diffusion of water through soil.

49. Capillary Tubes.—Fix upright in coloured water a few clean glass tubes whose bores vary in diameter from an inch down to that of thermometer tubing. It will be found that the water rises a little way up even the widest tube, whilst in the smallest it mounts an inch or more above the outside level. The smaller the bore the higher the water rises.

50. Osmosis.—When dry raisins are placed in water, they swell up just as dry seeds do. On the other hand, if fresh grapes are placed in a strong solution of sugar, they shrink. The swelling of the dried seeds or raisins and the shrinking of the fresh grapes are due to *osmotic pressure*.

If we place in a vessel of water a bladder filled with a strong solution of a substance having an "attraction" for water, *e.g.* sugar, a *large* amount of the water will diffuse (pass by osmosis) into the bladder (*endosmosis*), while a *small* amount of the solution will diffuse out (*exosmosis*). The weaker solution diffuses faster, and this continues until the same concentration is acquired, when it is equally rapid in both directions, and hence apparently ceases. Meanwhile considerable pressure is set up inside the bladder, owing to rapid endosmosis.

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[1] Area of a circle = ·785 × square of diameter.

51. Thistle-Tube Experiments.—(*a*) Get a thistle-tube ("thistle-funnel," with 18-inch tube, 3d. or 4d.), and prepare a strong (about 10 per cent.) solution of sugar, colouring it by adding red ink if the experiment is to be shown in a class. Get a butcher to clean, inflate, and dry a sheep's bladder for you; cut out a piece large enough to tie over the wide mouth of the tube, and soak it in water.

Plug the narrow end with a bit of plasticine, pour into the wide end enough solution to fill the head and an inch or so of the narrow part, tie over the mouth the piece of bladder, invert the funnel, and remove the plug of plasticine. Then fix the "funnel," head downwards, into the cork of a wide-mouthed glass jar containing water, so that the coloured sugar solution in the tube is level with the water (Fig. 14A). Observe the rise of the liquid in the tube of the funnel, also show that a little of the sugar solution diffuses into the water, by evaporating the liquid in the dish to dryness, when a small residue of sugar will remain. If the sugar solution used is strong enough, the presence of sugar in the water outside of the thistle-funnel may be detected by tasting.

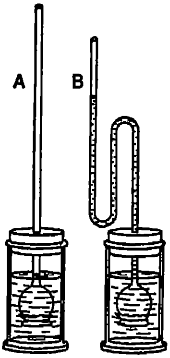

Fig. 14

(*b*) Repeat the experiment, using common salt (about 20 per cent.) instead of sugar in the bulb and distilled water instead of tap water in the jar. From time to time take a little water out of the jar, put it in a test-tube, and add a drop of silver nitrate; a white precipitate shows the presence of salt in the water.

When the liquid stops rising in the tube take the thistle-funnel out, replace the water with a very strong solution of salt, put the bulb in again, and note that the liquid now falls in the tube (why?)

(*c*) An interesting modification of the foregoing experiments can be made by having the salt or sugar solution in the jar and distilled or tap water filling the thistle-tube. What happens in this case?

52. Osmotic Pressure.—Careful experiments with suitable membranes have shown that the osmotic pressure set up by a 1 per cent. solution of saltpetre is enough to support a column of water over 100 feet high, i.e. equal to a pressure of 3½ atmospheres, or more than 50 lbs. per square inch. Some idea of osmotic pressure may be obtained by using apparatus fitted up like that shown in Fig. 18B (a thistle-tube like this costs about 6d.), the pressure being measured by the rise of the mercury in the bent tube. The pressure set up by endosmosis has an important application in connection with root-absorption and other processes in plant-life.

53. Properties of Water.—Water is absolutely essential in all the active life-processes of plants. We must, therefore, study the properties of water, so far as they bear upon plant-life

Water exists in the three states of ice, liquid water, and steam (or water vapour) It is never found in a state of purity in nature, because nearly all substances are more or less soluble in it Even rain-water contains gases dissolved from the atmosphere (oxygen, nitrogen, carbon dioxide, ammonia) Spring or river water contains various dissolved salts, which are carried into the sea by the rivers and there left behind, when the water evaporates to form clouds.

When water is boiled the dissolved gases are driven out of solution, and if the water is entirely evaporated the dissolved solids are left behind as a residue Thus it is clear that only the water evaporates, and if the water-vapour (or steam) is cooled, it condenses, and pure (distilled) water is obtained.

Water expands when heated from 4° C up to 100° C. (boiling-point), and contracts when cooled from 100° C. down to 4° C Below 4° C, however, it expands again, and at 0° C (freezing-point) turns into ice, expanding during freezing to $\frac{12}{11}$ths the volume of the water When a plant is exposed to great cold, the expansion of the water during freezing often forms cracks in the tissues The action of frost helps in forming soil from the underlying rock, and also breaks down the rough clods left by the plough into a fine seed-bed If water contracted on freezing, the ice as it formed would sink to the bottom, and thus a spell of cold weather would convert our rivers, lakes, and pools into blocks of solid ice

54. Conduction and Convection.—Water is a bad conductor of heat, but is rapidly heated uniformly throughout if *convection* currents are set up When heat is applied to the bottom of a vessel containing water, the lower layers, being heated, expand, become lighter, and rise to the surface, while the heavier cold water steadily descends to be warmed In nature, however, ponds and streams are warmed and cooled from the top, so that the surface layers may become quite warm while the bottom layers are very cold In winter time as the surface water cools and becomes heavier it descends, the warmer water rising from the bottom, and this goes on until all the water is at 4° C. Then the surface layers begin to expand and a layer of ice forms, which keeps in the heat of the water beneath Hence it requires very great and prolonged cold to freeze through a deep pond

(*a*) **Conduction.**—Load a piece of ice by twisting a piece of copper wire round it, and sink it in a long test-tube nearly full of water Fix the tube in an inclined position on a retort stand, and heat it near the top with a spirit lamp It will be found that the top may be boiled before much of the ice is melted

(*b*) **Convection.**—In a beaker of water strew some paper pulp or sawdust Place it on a piece of wire gauze on a tripod stand, and when the water has become nearly still, put the flame of a Bunsen burner under the middle of the beaker Note the ascent of the warm water up the middle of the beaker, and the indraught of cold water from the top and sides

55. Specific Heat.—Of all substances water has the greatest capacity for heat. The *specific heat* of a substance is the ratio between the amount of heat required to raise the temperature of a given mass of the substance 1° C and the amount of heat required to raise the temperature of an equal mass of water 1° C The same amount of heat that will raise the temperature of 1 lb of water from 0° to 1° C will raise 1 lb of sand from 0° to 5° C

Owing to its great specific heat, water absorbs much more heat in warming, and gives out much more heat in cooling, than an equal weight of almost any other substance. Hence the value of water in hot-water pipes, foot-warmers, etc Island countries enjoy a more equable climate than continental countries in the same latitude, because land is more easily heated or cooled than water

56. Latent Heat.—When ice at 0° C. has heat applied to it, its temperature does not rise so long as any ice is unmelted; the heat energy supplied is used up in changing the solid ice into liquid water. About 79 heat-units are required to melt 1 lb of ice into water at 0° C When water has been brought to the temperature of boiling, it ceases to become warmer so long as boiling continues, the heat supplied is used up in doing the work of changing water into steam About 537 heat-units are required to change 1 lb of water at 100° C into steam at the same temperature The amounts of heat required to change ice into water and water into steam are called the latent heats of ice and of steam.

There are some familiar effects connected with the magnitude of the latent heat of water After all the water in a pond has cooled to the freezing temperature, a long time elapses before any great thickness of ice is formed, even if the frost be severe. The great amount of heat latent in the water takes time to radiate One of the reasons why snow lies permanently on high mountains is that the latent heat of water is so great that the sun's rays are unable to provide sufficient heat to melt all the snow that falls in a year.

57. Unit of Heat.—To compare the heat capacity of any substance with that of water, we take equal masses, and we may take as *unit quantity of heat* the quantity required to raise a certain mass of water 1° C in temperature

The mass usually taken is 1 gramme, and the thermal or heat unit so defined is known as a *calorie* If it be more convenient in working out an example, 1 lb or 1 oz may be taken as the unit of mass instead of 1 gramme

58. Composition of Water.—Water is a *chemical compound*, consisting of two elements,[1] hydrogen and oxygen, which are chemically united This compound differs entirely in its properties from hydrogen and oxygen, which are gases except at extremely low temperatures

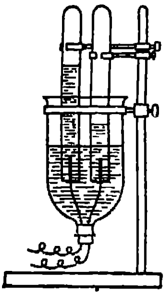

Fig 15—Analysis of Water by the Voltameter

This can be proved by passing an electric current through water, by means of a piece of apparatus known as a Voltameter (Fig 15) The current is produced by an electric battery (not shown in the figure), and brought to the water by one wire, and carried away by the other The wires end in metal plates projecting up into the water Over each of these plates is placed a test-tube, filled with water and with the open end downwards under the surface of the water in the vessel As soon as the current begins to pass, bubbles are seen to appear over the surface of the two metal plates These bubbles soon float up into the test-tubes, and the gases they contain accumulate at the top of each tube It will soon be seen that the formation of bubbles is much more rapid at one plate than at the other, and as the gases collect we find there is exactly twice as much of one as the other When enough has collected we can stop the current, remove the test-tube with the greater amount of gas, covering its open end with the thumb before lifting it out of the water, and then turning that end upwards On removing the thumb and applying a light, this gas is found to burn with a blue flame This gas is *Hydrogen* Examining the gas in the other tube in the same way, we find it does not burn, but it allows other substances to burn in it in a more active way than they do in the air This gas is in fact *Oxygen*, the constituent of the atmosphere which takes part in the process of combustion. We have thus *analysed* or split up water into two substances

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[1] An element is a substance which has never been separated into two or more different substances

That water is really composed of Oxygen and Hydrogen in chemical combination can be shown by the reverse process —*synthesis*—that is the production of water from Oxygen and Hydrogen. This is done by passing an electric spark through a mixture of the two gases in the proper proportions, when water is formed.

59. The Atmosphere.—As the life-processes of plants (and animals) depend on a supply of air, and are greatly influenced by changes in it, the properties and composition of air must be thoroughly understood by the student of plant-life Beans get most of their food from the air, directly or indirectly Water is brought to the roots in the soil as rain, carbon and nitrogen, two essential elements in the Bean plant's food, also come from the air, as we shall see later.

60. Air is Material and has Weight.—It is difficult for many young students at first to realise that air is as much a material thing as the water and earth around them Gases with striking properties do not present the same difficulty. The colour of chlorine, the odour of coal-gas, convince us of the reality of these. But the ever-present air, without odour, taste, or colour, occupies in the mind of the beginner a position quite by itself The difficulty is increased too by such familiar phrases as "empty bucket," "nothing in the jug," etc All will recognise that a stone must be removed before another body can be put in its place; some, that water is displaced when other bodies are dropped into it, but probably none are conscious of doing an exactly similar thing to air when they pour water into an "empty bucket"

Physicists tell us that *all* material things, or "matter" as they call it, possess weight If therefore we can show that air can be weighed, it will help to convince us of its material nature It might occur to you that this could be done by weighing a bag first empty and afterwards filled with air The ancient philosophers tried this way and found that the weight did not alter, they therefore concluded that air has no weight. This shows us the danger of making
out testing their truth in several w

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bag we will take a glass flask and use a delicate pair of scales, or balance, for the weighing.

Select a flask rather large and preferably round. Fit it with a rubber cork pierced by a glass tube 3 or 4 ins. long, over which is bound tightly a piece of rubber tube. Tie round the neck a piece of thin copper wire to hang the flask up by. Having seen that everything is quite dry and clean, hang the flask, together with another bit of wire, over the scale-pan of a balance, and very carefully weigh it.

Consider what we have weighed. There are flask, cork, glass and rubber tubes, three pieces of wire, and the air inside the flask.

Next suck out as much air as you can, using a glass mouthpiece so as not to wet the rubber tubing, which was weighed dry, and then double back the rubber tube, binding tightly the extra piece of wire round it to prevent air leaking back into the flask. Remove the mouthpiece and weigh the whole again.

The weight will now be found to be less than before. Since everything is present as at the first weighing, with the exception of the withdrawn air, it is reasonable to assume that the difference in weight represents that of the air sucked out.

But we can go farther than this. If you loosen the rubber tube whilst held beneath water, some of the latter passes into the flask, evidently taking the place of the removed air. Do this carefully, and measure the volume of water received by pouring it into a measuring vessel. The measurement evidently represents the volume of air sucked out, and we now know both weight and volume of this air. From your results calculate the weight of a litre of air; if your experiment has been carefully done, your answer should be somewhere near 1.3 gramme.

61. The Pressure of Air.—If, then, the air has, in common with solids and liquids, the property of weight, how great must be the downward pressure of the atmosphere, which extends to the height of a hundred miles above the earth! Air presses against everything it touches. The magnitude of the pressure is independent of its direction; it is as great *laterally* and *upwards* as it is *downwards*.

(*a*) The machine called an "air-pump" is designed to remove air from the interior of vessels, and it does so far more effectively than mouth suction. The strong glass vessel from which we remove more or less of the air stands on a greased glass plate, and is called the "receiver"; the grease makes an air-tight fit.

Place within this receiver a rubber bag only partly filled with air and with its mouth securely tied. The bag appears collapsed. But proceed to exhaust the receiver and note what happens. The bag fills out and the walls become *stretched*, evidently by the air left within it and whose pressure thus becomes apparent directly we remove a little of the air around it.

On allowing air to re-enter the receiver and exert its full pressure once more, the bag is squeezed back to its original limp state.

(*b*) Tie securely a piece of thin sheet rubber over the open top of the receiver. Grease the ground edge of the receiver before placing it on the plate of the pump Give a few strokes of the piston to remove a little of the air from the receiver, when evidence of outer air-pressure will be obtained

(c) Fill a small jar or tumbler with water, place a card over the mouth and invert the jar. Why does the water not run out?

62. The Barometer —The first actual measurement of the pressure of the atmosphere is due to Torricelli (1643), and his experiment resulted in the invention of the mercurial barometer.

A glass tube about 33 ins long and closed at one end is completely filled with mercury The open end is then closed with the thumb, the tube inverted into a cup of mercury, and the thumb then removed, care being taken not to allow any air to get into the tube The mercury at once sinks and leaves a clear space at the top of the tube, and the height of the column of mercury above the surface in the cup is found to be about 30 ins. or 760 mm The space above the mercury is practically a vacuum, it contains a minute quantity of mercury vapour Hence there is no pressure on the top of the mercury column. The pressure of the air on the mercury in the cup must be equal to that due to the weight of the column of mercury in the tube The height of this column therefore measures the weight or pressure of the atmosphere, and if the tube is furnished with a scale for reading off the height of the mercury, the apparatus is a mercurial barometer. If the tube is of uniform bore, and say 1 sq cm in section, the mercury in the column will weigh 1033 grammes; a water column of equal section and 76 cms high will weigh 76 grammes, and mercury is 13 59 times heavier than water So the air-pressure per sq. cm is 1033 grammes, or, in our system of weights and measures, with a tube 1 sq in in section, the mercury column (nearly 30 ins long) would weigh nearly 15 lbs —that is, the air-pressure is nearly 15 lbs per square inch

63. Air-Pressure Varies.—Having filled a tube a metre long with mercury and inverted it in a dish, if you measure the column from day to day you will scarcely ever find two succeeding measurements exactly the same Yet under ordinary circumstances it will always be somewhere between 28 and 31 ins. It is evident, therefore, that the air-pressure, though always considerable in amount, is not constant, but may vary between fairly wide limits. As these variations have considerable effect upon the weather, it is important that they should be constantly noted

64 Barometers —These are instruments designed for this purpose. There are two kinds, of which the **mercurial barometer** depends upon the principles just explained The simpler forms of this instrument resemble the bent tube (Fig 16), and are known as "siphon barometers." A scale for reading the length of the mercury column is either etched upon the tube itself, or is affixed behind it If, as rarely happens, the tube is constant in bore, the scale is necessary only for a few inches at the top. A rise or fall, say of 1 cm., really shows a difference in length of the column of 2 cms.

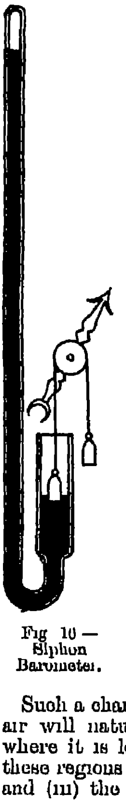


Fig 10 — Siphon Barometer.

"Cistern barometers" are practically straight tubes inverted in open vessels of mercury. In Fortin's barometer there is an arrangement for bringing the surface of the mercury in this vessel to a fixed position, so that the top reading only is necessary.

The **aneroid barometer** is now very commonly used, on account of its portability. No mercury is used in its construction. It consists of an air-tight metal box, generally disc-shaped, and almost exhausted of all air. The top is so flexible as to respond to the variations of the air-pressure upon it, and the slight movement in or out is magnified by a system of levers and communicated to a pointer which travels over a dial. The scale on the latter is so fixed that the indications of the pointer correspond with the heights shown by a mercurial barometer.

65. Use of Barometers in Forecasting the Weather.—If you examine a "weather chart" issued by the Meteorological Office, or that which appears daily in *The Times* newspaper, you will find upon a map of the British Isles a series of more or less parallel lines called "isobars." The number attached to each line shows the height of the barometer in inches at a given time for all places through which that line passes, supposing they are situated at the sea-level. Thus, from a number of readings taken at the same time by observers far apart, we learn another very important fact about air-pressure—viz. that its amount is never the same even over small areas. Fig 17 is a copy of a chart for January 12, 1905, from which you will see that, on that date and for the area shown, the pressure was greatest over central France and least over central Sweden.

Such a chart thus indicates (i) the regions of wind and calm—for the air will naturally move from those of high pressure towards those where it is low, (ii) the relative velocity of the wind—for the closer these regions are together the more rapidly will the air tend to move, and (iii) the direction of the wind. Contrary, however, to what we might expect, the wind does not blow directly across the isobars, but more or less parallel to them. It is found that in our northern hemisphere, if you turn your back to the wind, the low-pressure area will be upon your left hand. [See if this agrees with the chart, in which the direction of the wind is shown by the arrows.] And so by remembering the character of the wind which blows from any particular direction—*i.e.* whether it is dry or moist, cold or warm, etc.—the probable weather conditions of any particular locality on the date in question may be roughly determined.

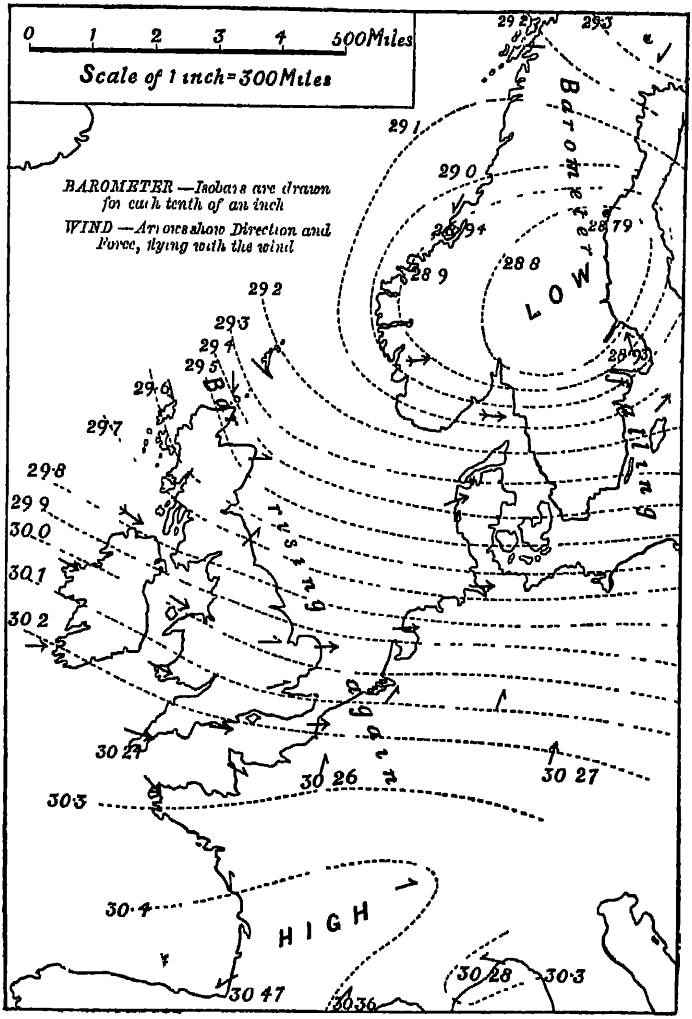
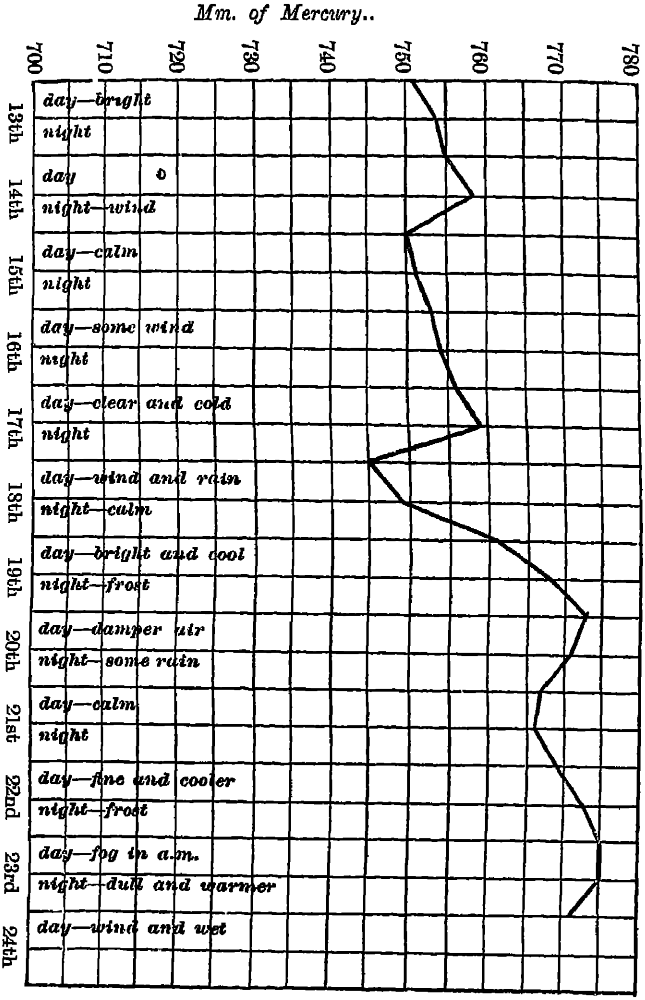


Fig. 17

[*Inserted by permission of the Controller of His Majesty's Stationery Office.*]



Uncorrected barometric readings at 9 a m and 9 p m and weather notes, January, 1906

Fig. 18.

But this is not prediction To be able to do this, and then only for a short time ahead, it is necessary to follow for some days previously the movements of the areas of low and high pressure, and note the direction they appear to be taking This requires expert skill and knowledge What is of more importance to the average individual is to be able to predict the weather for his own locality; and this can be done with some degree of accuracy only by watching carefully the behaviour of his barometer

The ordinary "weather glass" is a siphon barometer with a mechanical contrivance for magnifying the amount of rise and fall of the mercury On the exposed surface of the latter floats a glass weight connected with a freely hanging counterpoise by means of a thread passing over a pulley (Fig 16) The latter carries a pointer which plays to and fro over a dial inscribed "Fair," "Change," "Rain," etc. Too much reliance must not be placed upon these interpretations A little consideration will show that the important points to note are (i) the *direction*, and (ii) the *velocity* of the motion of the pointer

Generally speaking, a *steady* barometer points to a continuation of the weather conditions, a *rising* barometer points, if slow, to fine weather, if rapid, to unsettled weather, a *falling* barometer indicates wet, and if the fall be rapid, wind as well See how these statements agree with the weather notes in Fig 18. Make readings of the barometer daily, and record them on squared paper, connecting them to form a curve as shown in Fig 18, which is a portion of an uncorrected record for January, 1906 Daily notes on the accompanying weather changes are also given.

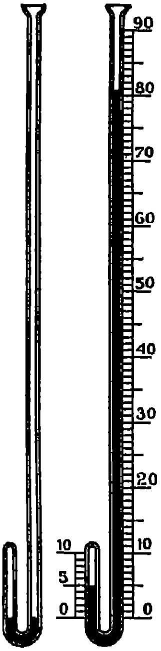


Fig 19 —Illustration of Boyle's Law

66. Effects of Pressure and Temperature on the Volume of Air.—Air agrees with other gases in obeying the law of Boyle and Mariotte—*i e.* that the volume of a given weight of gas varies inversely as the pressure to which it is subjected, provided the temperature remains the same That is, when the pressure on air is doubled, its volume is halved, and *vice versa*

This law may be verified by means of the bent tube (sometimes called Boyle's tube) shown in Fig. 19 The gas to be experimented on is placed in the shorter closed limb, and the quantity of mercury in the bend is adjusted so that the level, in each limb, is at the zero of the corresponding scale and also in the same horizontal line. Mercury is then poured into the long limb, and it is found that as the pressure on the gas in the closed tube is increased its volume diminishes, and by observing the volume corresponding to different pressures the law given above will be found true

It is well known that air expands when warmed Experiments have shown that dry air and other gases expand about $\frac{1}{273}$ of their volume at 0° C. for every increase in temperature of 1° C and contract by the same amount for every decrease of 1° C, provided that the pressure remains the same This is called the Law of Charles.

67 **Wind.**—The higher we ascend into the atmosphere the colder it becomes. The passage of the sun's rays through the air causes little elevation of its temperature, but the lower layers, receiving warmth from the quickly-heated soil, rise upwards, while the cooler air above, and that lying over the sea, stream into its place

The following experiment will serve to illustrate these convection currents of the air Make a hole towards each end of a well-fitting lid of a cigar-box Place a piece of lighted candle in the box exactly underneath one hole, and stand a glass chimney over both Now hold some smouldering brown paper over each chimney in turn, and note the direction of the air-currents Next, place a piece of cardboard over one chimney and make the same observations as before

68. Gaseous diffusion is the property of gases to mix thoroughly and completely even against gravity—*i e* a heavy gas will diffuse upwards and completely mix with a lighter gas, and a light gas will diffuse downwards and mix with a heavier one

Fill a glass jar with coal-gas over a burner and cover its open end, which must be kept downwards, with a plate of glass Set the jar on a jar of similar size and shape containing air, on removing the plate and allowing the gases to diffuse for about half an hour, the lower jar will contain as much coal-gas as the upper one and can be lighted Coal-gas is, of course, much lighter than air

69. Diffusion of Gases through Small Openings—The same result would be obtained, after a longer time, if a partition of porous material, such as unglazed earthenware, were placed between the jars This can be shown by various simple experiments.

(*a*) Take a piece of glass tubing some ten or twelve inches in length, and proceed to close the one end with a layer of plaster of Paris in the following manner First mix a little of the plaster with water, so as to form a thick cream, spread this mixture uniformly on a plate to the depth of an eighth or three-sixteenths of an inch. Then press down in it one end of the clean dry glass tube, and allow it to remain undisturbed until the plaster has "set" (become solid), which should take place in ten or fifteen minutes. Slide the end of the tube off the plate, and set it aside for a few hours to dry

Cover the plaster partition with a cap of tinfoil and fill the tube with coal-gas, or with hydrogen [1] Place the inverted tube with its lower end in water, about half an inch below the level of the surface. Remove the tinfoil cap and immediately the water is seen to rise within the tube against the action of gravity until the tube is about two-thirds full of water

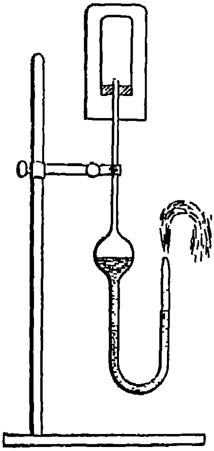


Fig 20

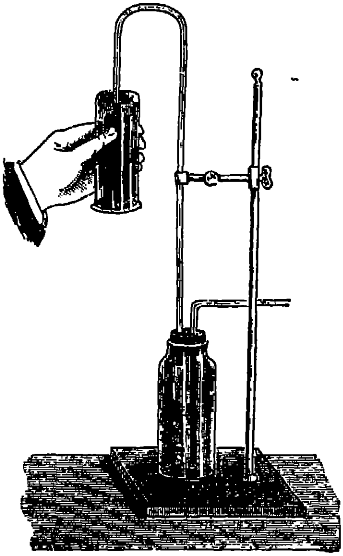


Fig 21.

(*b*) As a converse experiment, the tube may be filled with carbon dioxide,[2] when the level of the gas descends and displaces the water altogether from the tube.

These experiments may be demonstrated by using the apparatus shown in Figs 20 and 21 respectively

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[1] Prepared by acting on zinc-filings with dilute hydrochloric or sulphuric acid.

[2] Prepared by acting on limestone-chips with an acid, or obtained by charging a Sparklet siphon without putting in any water.

In the first experiment the hydrogen, being so much lighter than air, diffuses out through the diaphragm nearly four times as rapidly as the air diffuses in; the consequence is that the volume of gas in the tube rapidly lessens and the water rises

The rate of diffusion of gases is inversely as the square root of their density. Hydrogen is about one-sixteenth as dense as air, while the density of carbon dioxide is about one and a half times that of air The rate of diffusion of carbon dioxide is about four-fifths that of air

70. Composition of the Atmosphere.—The gaseous envelope which surrounds the earth consists chiefly of a mixture of nitrogen and oxygen. With these are associated argon (a gas which is so like nitrogen that only within the last few years has the distinctness of the two been realised), very variable amounts of water-vapour, carbon dioxide, and minute quantities of various other gases (ammonia, nitric acid, etc), according to the locality from which our specimen of air is chosen. Floating through this mixture are innumerable minute *solid* particles, which are collectively known as "dust," but are of very diverse kinds

From whatever locality the air has been obtained, the relative proportions of nitrogen and oxygen exhibit only slight variations, there being about four times as much of the former as of the latter.

When metals are heated in the air, they gain in weight, the ash (or *calx*, as it was formerly called) is heavier than the original metal. If a piece of magnesium ribbon is burnt in a closed vessel containing air and standing over water in a dish, the water rises in the vessel, showing that some of the air (about a fifth of the original volume) has united with the magnesium Various other experiments prove that air consists of an active gas (oxygen) forming about a fifth of its volume, and of an inactive gas (nitrogen) forming about four-fifths of its volume. All ordinary processes of burning are accompanied by the absorption of oxygen from the air and its union from the burning substance. In most cases it is difficult to recover oxygen from the calx of a metal; partly on this account the composition of air was not understood until late in the eighteenth century

In 1774 Joseph Priestley happened to heat some "red precipitate" with a "burning-glass" or lens, and found that a gas possessing remarkable properties was set free In the same year that he made this discovery Priestley went to Paris and showed his experiment to the chemists there Among them was the famous Lavoisier, who had proved that when metals are heated in air, the ash or scale (calx) formed is heavier than the metal and not lighter, as the old philosophers had assumed This great chemist understood its significance, for he presently *made* some of the scarlet powder by heating mercury almost to its boiling-point whilst exposed to a *measured volume* of air.

In the first experiment the hydrogen, being so much lighter than air, diffuses out through the diaphragm nearly four times as rapidly as the air diffuses in; the consequence is that the volume of gas in the tube rapidly lessens and the water rises.

The rate of diffusion of gases is inversely as the square root of their density. Hydrogen is about one-sixteenth as dense as air, while the density of carbon dioxide is about one and a half times that of air. The rate of diffusion of carbon dioxide is about four-fifths that of air

70. Composition of the Atmosphere.—The gaseous envelope which surrounds the earth consists chiefly of a mixture of nitrogen and oxygen With these are associated argon (a gas which is so like nitrogen that only within the last few years has the distinctness of the two been realised), very variable amounts of water-vapour, carbon dioxide, and minute quantities of various other gases (ammonia, nitric acid, etc.), according to the locality from which our specimen of air is chosen Floating through this mixture are innumerable minute *solid* particles, which are collectively known as "dust," but are of very diverse kinds

From whatever locality the air has been obtained, the relative proportions of nitrogen and oxygen exhibit only slight variations, there being about four times as much of the former as of the latter.

When metals are heated in the air, they gain in weight; the ash (or *calx*, as it was formerly called) is heavier than the original metal. If a piece of magnesium ribbon is burnt in a closed vessel containing air and standing over water in a dish, the water rises in the vessel, showing that some of the air (about a fifth of the original volume) has united with the magnesium Various other experiments prove that air consists of an active gas (oxygen) forming about a fifth of its volume, and of an inactive gas (nitrogen) forming about four-fifths of its volume. All ordinary processes of burning are accompanied by the absorption of oxygen from the air and its union from the burning substance In most cases it is difficult to recover oxygen from the calx of a metal, partly on this account the composition of air was not understood until late in the eighteenth century.

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Specks gradually appeared on the bright metallic surface, whilst the bulk of the air became less. At the end of twelve days he scraped off the rusty deposit, and, heating it strongly in a tube, *obtained the same volume of gas as the air had lost*, whilst the scarlet powder was transformed into the liquid metal again.

Plainly, then, this new gas, with its remarkable properties, is not merely a modified form of air, but is a distinct substance. Lavoisier gave to it its name oxygen, the "acid-former," for reasons which will be seen later. "Red precipitate" is a compound of mercury and oxygen, its chemical name being "oxide of mercury"

(*a*) Bend a piece of wire twice at right angles, to form a J shape, and to the end of the shorter limb fix a piece of cotton-wool. Get ready a glass jar and a basin containing water. Soak the cotton-wool in alcohol (methylated spirit), set fire to it, invert the jar over the flame and lower it into the water The flame soon goes out and the water rises inside the jar. Why?

(*b*) Into a hard-glass tube introduce sufficient "red precipitate" to cover a threepenny piece, and hold it in the hottest part of the Bunsen flame When cold the substance is scarlet and glittering, but on heating it becomes black. Take the tube from the flame, let it cool, and notice what happens. The scarlet colour is recovered Evidently the change was not due to *burning*.

Have by you a splinter of wood long enough to reach down to the bottom of the tube, and heat the latter again as long as any of the oxide remains. Whilst the deposit is forming in the tube, ignite the splinter, blow out the flame, and thrust the glowing end down into the tube Observe that the glowing splinter bursts into flame and burns more brightly than in common air The colourless gas in the tube cannot be ordinary air it is *oxygen*. Now scrape off the mirror formed in the tube with the clean end of the splint You obtain a liquid metallic globule of "quicksilver," or *mercury*

Oxygen is most readily prepared by heating potassium chlorate (a compound of potassium, chlorine, and oxygen)

71. Preparation of Oxygen.—(*a*) Heat some potassium chlorate in a tube until it appears to boil. It is not really boiling, or some of the substance should condense in the cool part of the tube. A gas is escaping. Test it with a glowing splinter.

(*b*) About one-quarter fill the tube with a mixture of two parts by weight of potassium chlorate and one of manganese dioxide. Oxygen will come off from this more readily than from the chlorate alone; that is, at a lower temperature than was required to decompose the chlorate alone. After all the oxygen is expelled the manganese dioxide remains, apparently unaltered, mixed up with the residue As the gas is obtained so easily, we will collect some jars of it and examine its properties.

(*c*) Bend a glass tube, about 1 ft. long, to the shape shown in Fig. 22, and insert the longer end through a cork fitting a hard-glass tube closed at one end, about 6 ins. long and 1 in. in diameter. Pour sufficient water into a "pneumatic trough" to cover its shelf by at least half an inch. Fill one large jar and four smaller ones with water and invert them in the trough. Have ready some ground-glass covers to be placed over the mouths of the jars when filled with gas.

Fig. 22.

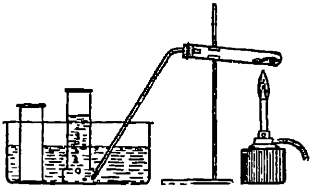

Fig. 23.

About one-quarter fill the fitted tube with the mixture made, and fix it horizontally in the jaws of a clamp, so that the delivery tube just dips under the shelf of the trough, as shown in Fig. 23. Use a small flame to heat the mixture, and move it to and fro along the tube to avoid getting too high a temperature. A few bubbles of air escape at first, but soon oxygen comes over rapidly. At once place a jar in position on the shelf, and, when it is filled, quickly cover its mouth while still under water with a glass plate, and replace it by a second jar, and so on.

72. Experiments with Oxygen.—Now try the effect of burning in oxygen three non-metallic elements (sulphur, phosphorus, carbon) and two metallic elements (sodium, iron), using the five jars of the gas which have been obtained.

1st jar (small). Fill the bowl of a deflagrating spoon with powdered *brimstone* and ignite it, noting flame and odour. Plunge it into the jar, and note that the brass plate fits closely (Fig. 24). When the action ceases, replace the glass cover. The flame and odour differ only in intensity from those first obtained. The sulphur has more or less burned away. Plainly the choking gas formed in both cases is due to the union of sulphur with oxygen. It is an oxide of sulphur. Pour a few drops of blue litmus solution[1] into the jar: it turns red, showing that an **acid** is present Invert the jar in water and remove the cover the water rises as it readily dissolves the new gas.

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[1] *Litmus* is a colouring matter which occurs in certain Lichens, and is very sensitive to the action of many chemical substances. It turns red in acids, and substances which turn it red are said to have an *acid reaction*: it turns blue in alkalies, or in substances having an *alkaline reaction*; and it is unaffected by water and many other substances which have a *neutral reaction*. *Blue litmus paper* is prepared by dipping unglazed paper in a solution of litmus (obtained by boiling commercial litmus with water and filtering). *Red litmus paper* is prepared by adding just sufficient acid to a solution of litmus to turn it red and then dipping unglazed paper in the liquid and drying it.

Burn off all the sulphur remaining on the spoon before proceeding.

2nd jar (small) Cut off from some yellow phosphorous, *held below water*, a piece not bigger than a pea, and transfer it on the point of a knife to the spoon Dry it by touching it with a bit of filter paper, and watch it for a few seconds White fumes with a peculiar odour are given off, the phosphorus is already reacting with the air.

Touch the phosphorus with a warm glass rod and plunge it at once into the oxygen, keeping the brass plate well down on the jar The white fumes are particles of solid *oxide of phosphorus*, and are poisonous. What becomes of the fumes? Test the water-drops on the side of the jar with blue litmus paper. Evidently oxide of phosphorus, too, is acid-producing.

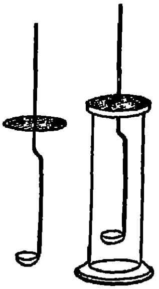
Fig 24

3rd jar (small) Wire a bit of *charcoal* to the end of a deflagrating spoon, and place it in the oxygen for a short time Withdraw it, and note that no carbon dioxide can be detected. Cold charcoal does not react with oxygen Now make the charcoal red-hot and watch it when removed from the flame It does not go on burning as the other bodies did Make it glow again and introduce it into the oxygen The charcoal burns brilliantly and some of it disappears, but no odour or fumes are detected. Pour water into the jar, shake it, divide the liquid into two parts, test the first with blue litmus, and the second with lime-water. Carbon dioxide has been formed, and this oxide is acid-forming too

4th jar (small) Examine *sodium*, noting its lustre when freshly cut and its lightness This metal oxides so rapidly in air that it must be preserved in liquid which contains no oxygen, and whose specific gravity is, of course, less than that of the metal For these reasons liquid paraffin is often used. Sodium reacts violently with water; do not handle it with wet fingers.

Heat a bit of the metal strongly in the spoon, then plunge it into the oxygen It burns brightly, forming white fumes of sodium oxide which dissolve in water. Examine the solution with litmus just coloured red with a drop of acid. The litmus at once becomes blue, indicating the presence of an **alkali.** Caustic soda is present.

5th jar (large) Introduce through a funnel sufficient sand to cover the bottom of this jar half an inch deep Roll 8 or 10 ins. of thin *iron* wire round a glass rod to form a spiral, fasten a bit of match to one end, and fix the other end to the deflagrating spoon. Light the match and plunge the wire into the jar. The wire burns—often with beautiful sparkling—whilst white-hot globules of "burnt iron" (iron oxide) fall upon the sand.

73. Properties of Oxygen.—We have found that—

(i) the oxides of non-metals, like sulphur, phosphorus, and carbon, yield acid solutions with water, but

(ii) the soluble oxide of a metal gives an alkaline solution.

Lavoisier was not aware of this latter fact, but it was his knowledge of the former that caused him to give the name oxygen ("acid-former") to the gas

Oxygen is only slightly soluble in water (100 c cs of water at 0° C. dissolve about 5 c cs of oxygen) It does not burn, but is a supporter of combustion; all substances that burn in air burn more vigorously in oxygen.

74. Nitrogen.—The inactive portion of the air consists chiefly of nitrogen. No direct simple test can be given for the detection of nitrogen in the free condition, because it does not readily react with chemical reagents. It forms about a fifth of the volume of the air, and is neither inflammable nor a supporter of combustion It has no action on lime-water nor on litmus paper By the action of intense heat, or that of an electric current, however, it is caused to combine with oxygen, forming brown fumes of oxide of nitrogen, which dissolve in water to form nitric acid

Nitrogen is a very important element in the nutrition of plants, since the living substance (protoplasm) of all plants (and animals) contains nitrogen. Most animals obtain nitrogen in the form of complex organic substances (proteids); most plants obtain it in the form of simple inorganic substances (chiefly nitrates). Most plants are unable to use the nitrogen of the air in making food, but this power is possessed by some Bacteria, and probably the whole of the combined nitrogen found in nature (chiefly as nitrate of soda and potash) has been formed from the air by the action of Bacteria.

The composition of air varies very little under different circumstances; but even such small variations as are found in its composition do not occur in the case of chemical compounds

Nitrogen and oxygen retain their characters with slight modification in air, and *a mixture of the two gases in the proper proportions shows precisely the same characters in all respects as air* No heat is evolved when they are brought together, nor does any contraction in volume take place.

75. Water contrasted with Air.—Both air and water have been shown to consist of two gases air, of nitrogen and oxygen; water, of hydrogen and oxygen. It is true the constitutents of air cannot be distinguished by the microscope, and diffusion prevents their separation into a heavier and lighter layer. Small quantities can, however, be partly separated by simple solution in water (for oxygen dissolves more readily than nitrogen),[1] and also by other physical means. But air is formed directly nitrogen and oxygen are *mixed* together, and there is no evidence of chemical reaction, such as rise of temperature, explosion or burning, or alteration in volume, which usually accompany *reaction* between gases. Further, the known gaseous compounds of nitrogen and oxygen are nothing like air in their chemical properties for one (nitrous oxide) is the anæsthetic so frequently used by dentists, and the other (nitric oxide) on exposure to air forms poisonous brown fumes They are totally different also from either of the constituents of air

The properties of air, on the other hand, are intermediate between those of oxygen and nitrogen. To a certain extent it resembles both. Thus it supports combustion like oxygen; but not so actively as the pure gas, a modification we might expect from the large proportion of inert nitrogen mixed with it.

A mixture of hydrogen and oxygen, however, is not water. It becomes water only on the elevation of its temperature to the ignition point of hydrogen, when the usual accompaniments of chemical action referred to above become manifest. The properties of the steam produced, too, are altogether different from those of either hydrogen or oxygen It does not burn, neither does it support the combustion of ordinary inflammable bodies, and when cooled it condenses to a liquid state, which makes the difference more striking still Both the elements are present in the steam, yet no longer separate and independent, but united by some mysterious force which we call chemical attraction

76 How to remove Oxygen from Air.—The following experiment gives a useful method for depriving air of its oxygen, or of measuring the volume of oxygen present in air Into a glass tube of about 100 c cs capacity pour some 20 to 30 c cs of solution of caustic soda, made by diluting that ordinarily used for analysis with twice its volume of water. Next, add as much pyrogallol as can be taken upon a penny piece (photographers will know this light fluffy powder as "pyrogallic acid") Close the tube at once with a rubber cork, and mark the height of the liquid with a rubber band Shake up occasionally for at least five minutes, then open the tube below water contained in a tall jar. Water enters; and if you sink the tube till the level of the water inside and outside is the same, marking the position with another band, the remaining air will be found to occupy four-fifths of the original volume. On testing it as before it will be found to be nitrogen.

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[1] When air is shaken up with water, twice as much oxygen as nitrogen is dissolved (100 c.cs. of water at 0° C. dissolve about 5 c.cs. of oxygen), so that air dissolved in water consists of one volume of oxygen with two volumes of nitrogen.

77. How Air is changed by the Burning of a Candle.—Inve a dry glass jar over a burning candle, both being placed on a tab After burning for a few seconds, the flame gradually grows less a soon goes out Repeat the experiment with another jar lifted a sh distance from the table; fresh air can now enter, and the burn continues The extinction of the candle in the first case could n have been due to *destruction* of the air; since the fit is not air tig more air would have been pressed beneath the jar It evident remains full of "air" of some kind, yet differing from fresh air T slightly raised jar not only admitted fresh air, but allowed the chang air to escape, on account of convection currents caused by the fla and by diffusion beneath the jar

Note the dewy appearance on the inner surface of the first ja suggesting the presence of water Sprinkle upon it a few grains anhydrous copper sulphate, a white powder, the latter becomes blu showing the liquid to be water The jar and candle were both dry first; whence then comes the water?

Plunge a lighted taper into the jar, it is extinguished Take a dr of clear lime-water (made by dissolving a little lime in water and f tering the muddy liquid) on the end of a glass rod and hold it for a fe seconds in the air; it shows no change Now lower it into the jar; becomes cloudy, and gives us further evidence that the air has unde gone a change

We have thus found that a burning candle does not destroy the ai but so alters it that (1) another candle cannot burn in it, (2) it turns drop of clear lime-water milky

78. Carbon Dioxide in Air.—The change in the lim water is caused by a gas called carbon dioxide, which con bines with the lime-water to form carbonate of lime (chalk the particles of chalk producing the milky appearance Tha carbon dioxide is present in ordinary air can be shown by simple experiment

(*a*) Expose to the air some *clear* lime-water in a clock glass until white film of carbonate of lime appears on the liquid If you ca collect sufficient of the solid after pouring off the water, the gas ma be expelled again with effervescence by adding a drop or two of dilut hydrochloric acid

(*b*) Fit up a bottle with a cork bored with two holes; through on hole pass a ⅂-shaped piece of glass-tubing reaching nearly to th bottom of the bottle, through the other hole a similar tube reaching little below the lower surface of the cork Pour clear baryta-water (o lime-water) into the bottle, so that it stands at least a clear inch belo the opening of the short tube. Connect the longer tube with stou rubber-tubing to an aspirator (Fig. 25) or a filter-pump attached to water-tap, and draw air through What happens?

(*c*) To account for the presence of this gas in the air perform the following experiments

Draw in a long breath and gently force it out through a glass tube dipping into lime-water contained in a test tube

Shake up some lime-water in a fairly large jar, or bottle, filled with ordinary air and covered with a glass plate Is there any milkiness? Now burn a taper, or candle, or splinter of wood in the jar, and afterwards shake up the lime-water

79. Water Vapour in Air.—That water vapour is present in the air even on the driest day can be proved by simple experiments It is not difficult to see where this water vapour comes from, since water is constantly evaporating from the surface of the sea and other sheets of water It can be proved by experiment that a given volume of air at a given temperature cannot contain more water vapour than a certain fixed quantity—*e g.* 1 cubic metre of air at 15° C cannot contain more than 12 8 grammes of water vapour When the air contains this maximum amount of vapour it is said to be saturated.

The higher the temperature of the air, the more vapour is required to saturate it, so that warm air may, without being saturated, contain more vapour than is sufficient to saturate it at a lower temperature If this air is cooled to this lower temperature, the excess of vapour will condense into small or large particles of water, sufficient vapour remaining to saturate the air If the air is cooled to a still lower temperature more vapour must condense, and so on

Many of our weather phenomena, such as clouds, mist, rain, etc , are produced by the condensation of water vapour Take, for instance, the formation of dew After a hot day the leaves of plants (and to a less extent the soil) cool, by radiation, more rapidly than the atmosphere The lowest layers of air then become cooled by contact with the leaves and soil. Should the surface temperature fall below that at which the vapour in the overlying air is saturated, condensation takes place and the excess moisture is deposited as *dew.* The temperature at which this takes place is called the *dew-point*

(*a*) Leave a dish containing some pieces of fused chloride of calcium exposed to the air for some time. The pieces become moist, having absorbed water vapour from the air If the dish and its contents be weighed before and after being exposed, the weight of water vapour absorbed will be obtained.

(*b*) Expose some anhydrous copper sulphate in a watch-glass , it soon turns blue, by absorbing water vapour.

80. Relative Humidity.—*Hygrometry* deals with all measurements connected with the state of the air as regards the moisture present in it We speak of the air as being *dry* or *moist* according as we think it contains little or much moisture, but the condition of the air, in relation to dryness or moisture, involves (1) the quantity of vapour *actually present* in the air, (2) the quantity of vapour necessary to *saturate* the air under the same conditions, and it is on the *ratio* of these two elements that our sensations of dryness and moisture chiefly depend, and not on the first alone Thus the air in a warm room may really contain more aqueous vapour than the outside air and yet be *drier*, because the amount required to saturate it is so much greater; for we have seen that the mass of vapour required to saturate a given space increases with the temperature, and is independent of the presence of air or other gas in that space.

The hygrometric state of the air, considered as the ratio of the mass of aqueous vapour actually present in a given volume to the mass of vapour required to saturate the same volume, at the same temperature, has been called the **humidity** or **relative humidity** of the air, and is usually expressed either as a ratio or as a percentage For example, if a cubic metre of air at a particular temperature contain 10 grammes of aqueous vapour, and if 30 grammes are required to saturate it at the same temperature, then the relative humidity is $\frac{1}{3}$, or 33·3 if expressed as a percentage.

81. Direct Determination of Relative Humidity.—In order to determine the relative humidity of the air, in the way explained above, it is evident that we must determine, by actual experiment, the mass of vapour really present in a given volume of air, and must also calculate the mass of vapour required to saturate the same volume at the same temperature

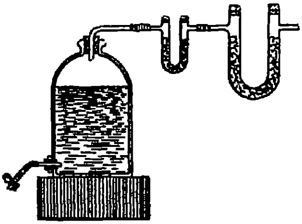
Fig. 25.

Referring to Fig 25, fill both U-tubes with pieces of fused calcium chloride, then weigh the larger one with its contents. Next fill the jar (of some 10 litres capacity) with water, and securely connect tubes and jar in the position shown. Allow all the water to trickle *slowly* out of the jar This will give the volume of the air passing through the large U-tube, providing all joints are air-tight. (A jar used in this way is called an "aspirator." It may be refilled and the operation repeated if necessary.) The weight of water abstracted from the air can be found from the increase in weight of the larger U-tube. The use of the smaller U-tube is to prevent any water vapour getting back from the vessel to the weighed tube.

82. Wet- and Dry-Bulb Hygrometer.—This instrument, sometimes called *Mason's hygrometer*, consists of two exactly similar thermometers, mounted on the same stand in such a way that the air can circulate freely round their bulbs. One thermometer is used merely to give the temperature of the air, the other has its bulb covered with muslin, which is kept moist by a wick dipping into water (Fig. 26). The wet-bulb thermometer gives a lower reading than the other. This is known to be due to the abstraction of heat from the bulb by the evaporating water. But evaporation can proceed only in unsaturated air, and although this is always the case in nature, yet the saturation-point may at certain times be much more nearly approached than at others. Then evaporation will be slower, and the differences in the readings of the thermometers will be small. But these differences, increasing with increased evaporation, are thus seen to vary inversely with the relative humidity. To obtain good comparisons, the instrument should be placed out of draughts.

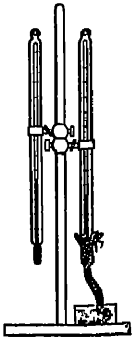

Fig. 26

Readings of the wet and dry bulbs were taken daily at 9 a.m. and 9 p.m. during February and July, and at each of these times the weight of water which had evaporated from an open dish during the preceding 12 hours was recorded. The results are expressed graphically by the curves of Fig. 27.

The *A* curves show the average differences of temperature between the wet and dry bulbs in degrees C. The *B* curves show loss of weight of water during the same times in grammes. The same shallow vessel was used in both observations and its sides were vertical.

The results distinctly show that—

(i) the greater the rate of evaporation, the greater the difference in the reading of the wet and dry bulbs, and

(ii) greater evaporation goes on in summer than in winter.

Make a wet- and dry-bulb hygrometer, and with it make similar observations over an extended period, and tabulate the results. A small shallow crystallising dish does well to contain the water.

83. Regnault's Hygrometer.—This consists (Fig. 28) of a glass tube *T*, closed below by a thin silver cap *S*. Its mouth is fitted with a cork carrying a thermometer *t* and a piece of tubing *d*, *both passing down nearly to the bottom of the tube.* To use the instrument ether is placed in the tube, and a current of air is drawn through by the aspirator *A*; entering by *d*, the air bubbles through the liquid and enters *A* through the side tube *e* and the vertical tube *V*. This passage of air through the ether in *S* causes rapid evaporation to take place; the temperature of the liquid, therefore, falls, and ultimately the aqueous vapour in the air condenses on the surface of *S*. The temperature is then read. This will be below the dew-point, as no dew is seen till a perceptible quantity has formed The aspirator is now shut off, the temperature of S rises, and when the last trace of dew vanishes the temperature is again read The mean of the readings is the dew-point

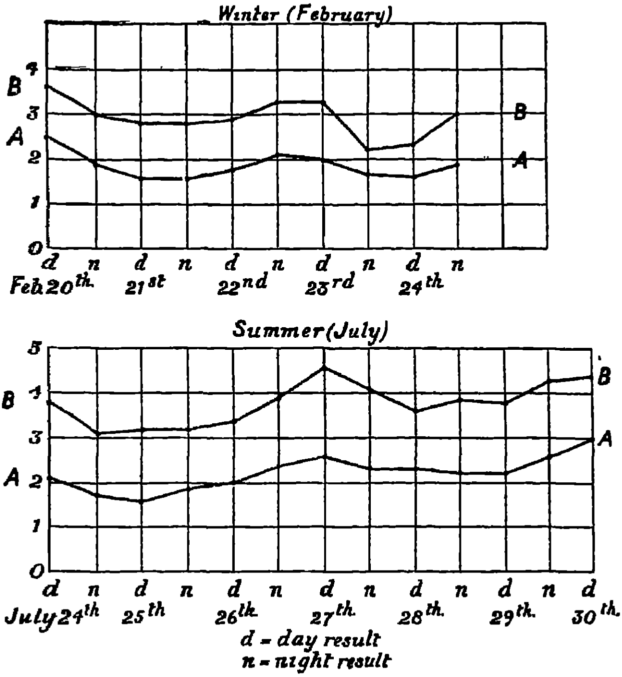

Fig. 27.

By regulating the current of air the cooling of the liquid in S may be made sufficiently slow to note, with accuracy, the temperature at which the film of moisture commences to form on S. This observation is usually further facilitated by having a second tube S', similar to the hygrometer tube, supported on the same stand, in such a position that the appearance of the two silver caps may be easily contrasted, and the dimness due to the deposition of moisture on S more readily detected. S' is not, however, an essential part of the instrument. it has no connection with S or V, and serves only for comparison, as explained above, and to carry a thermometer t', which gives the temperature of the air.

In order to obtain good determinations with any form of dew-point hygrometer, the experiment should be repeated until the temperatures of appearance and disappearance of the film of moisture on the cold surface are very nearly the same, say within 5° of each other.

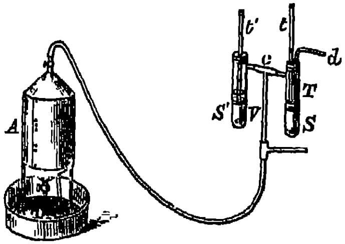

Fig. 28

The table given below shows the pressure of aqueous vapour at various dew-point temperatures. If h denote the relative humidity of the air, f the maximum pressure of aqueous vapour at the dew-point, and F the maximum pressure at the temperature of the air, then—

$$h = \frac{f}{F}.$$

For example, if air, at 15° C., be cooled down to 10° C., before condensation commences, then—

$$h = \frac{f_{10}}{f_{15}} = \frac{9\cdot1}{12\cdot7} = 0\cdot72\text{; that is, } 72\%$$

84. Table showing Pressure of Water Vapour (F) **in mm. and Mass of Water** (M) **in grammes contained in 1 cubic metre of Air, with Dew-Point** (T). (*Regnault and Magnus.*)

T	F	M	T	F	M	T	F	M	T	F	M
	mm.	gr.		mm.	gr.		mm.	gr.		mm.	gr.
−10°	2·0	2·1	0°	4·6	4·9	10°	9·1	9·4	20°	17·4	17·2
− 9	2·2	2·4	1	4·9	5·2	11	9·8	10·0	21	18·5	18·2
− 8	2·4	2·7	2	5·3	5·6	12	10·4	10·6	22	19·7	19·3
− 7	2·6	3·0	3	5·7	6·0	13	11·1	11·3	23	20·9	20·4
− 6	2·8	3·2	4	6·1	6·4	14	11·9	12·0	24	22·2	21·5
− 5	3·1	3·5	5	6·5	6·8	15	12·7	12·8	25	23·6	22·9
− 4	3·3	3·8	6	7·0	7·3	16	13·5	13·6	26	25·0	24·2
− 3	3·6	4·1	7	[illegible]	7·7	17	14·4	14·5	27	26·5	25·6
− 2	3·9	4·4	8	8·0	8·1	18	15·4	15·1	28	28·1	27·0
− 1	4·2	6·4	9	8·5	8·8	19	16·3	16·2	29	29·8	28·6
− 0	4·6	4·9	10	9·1	9·4	20	17·4	17·2	30	31·6	30·1

85. Cooling caused by Evaporation.—It is well known that whenever a liquid is converted into vapour, whether by evaporation or boiling, heat is absorbed in the process. Whether heat be deliberately applied or not, evaporation still proceeds—*e.g.* ponds and puddles dry up. The heat necessary to maintain this continuous process comes from the remainder of the liquid or any body with which the liquid is in contact Thus a liquid by evaporating tends to cool itself and surrounding bodies. Several experiments have been devised to illustrate this fact

(*a*) Pour a few drops of ether on to the hand, and then wave the hand This will produce a sensation of cold, as ether evaporates very readily

(*b*) Pour a few drops of water on a wood block, and stand in this water a beaker containing a little ether Then blow with a bellows into the beaker to quicken the evaporation of the ether The water will freeze and cement the beaker to the wood.

86. Conditions favourable to Evaporation.—Evaporation is increased by anything that helps in the formation of vapour at the free surface of the liquid. The rate of evaporation is therefore favoured by dryness of the air, low atmospheric pressure, high temperature, both of the liquid and of the air, large extent of free surface of liquid; low boiling-point of liquid, renewal of air in contact with surface of liquid

87. Rain-Gauge —We know that the effects of a short shower are soon over · the roads and fields soon "dry," as we say, though this drying is only partly the result of evaporation, and largely the result of the water flowing away into watercourses and sinking into the earth If we could prevent the water that falls as rain from either evaporating, flowing off, or sinking in, we should find it accumulating, till in time it was of measurable depth We could then say that during a given time, say a month or a year, there had been so many centimetres (or inches) of rainfall This is what is actually done, on a small scale, by the rain-gauge

An ordinary rain-gauge consists merely of a metal cylinder, into which there fits a metal funnel, and of a glass vessel properly graduated. The object of the funnel is simply to check evaporation. As the actual area whose rainfall is measured is the area of the top of the cylinder, it would be sufficient to measure the depth of the water that accumulated at the bottom, but it is better to pour off the water into a glass vessel of less diameter, or to use a tube to collect the water (in many rain-gauges this is done, the ratio of surface between receiver and tube being 10 to 1), for then the height of the water is magnified, and so can be determined more accurately

In using a rain-gauge, it is important that it should be placed in a thoroughly exposed position, so as not to be sheltered by any up-standing object, such as a house or tree

88. The Soil is the medium in which land-plants may place their roots in such a manner as to enable them to stand erect in the light and air, and it is a storehouse of moisture for the use of plants. The productiveness of a soil depends largely on the amount of water it can hold, and on the readiness and completeness with which plants growing in it can withdraw the water for their use as required The soil is also a storehouse from which plants get the necessary ash ingredients of their food, the lime, potash, phosphoric acid, etc, which are formed by the breaking-down and solution of the soil-grains. The soil is also a laboratory in which various lowly plants (fungi and bacteria) are at work breaking down dead organic matter, and converting it into nitric acid and other forms in which it becomes available for the use of higher plants

89 The Earth's Crust —By this term we understand the portion of the earth's exterior which comes within our observation Its thickness is about 10 miles, so that it represents only a relatively thin layer Since the average density of the crust (2 8) is just about half that of the earth as a whole, it is clear that the interior must have a very high density, and cannot have either the same chemical composition or physical characters as the outer layer

90. Rocks —A rock may be defined as any mass of naturally occurring solid substance forming part of the earth's crust Rocks may be divided into two main groups (1) those formed by cooling, at or near the earth's surface, of masses of molten material, and termed *igneous* rocks; (2) those formed by the accumulation of material derived from pre-existing rocks, and termed *aqueous*, *stratified*, or *sedimentary* rocks To the former group belong granites and basalts, and most of this group are crystalline rocks To the latter group belong sandstones, clays, limestones, most of these have been laid down under water, and they are not usually crystalline

91. Elements of the Earth's Crust.—Comparatively few elements enter into the composition of the common rock-forming minerals (quartz, felspars, micas, hornblende, augite, olivine, calcite, gypsum, kaolin, iron ores, etc.), and about eight out of the eighty elements now known to chemists form about 97 per cent. of the earth's crust The percentages of these elements are oxygen 50, silicon 25, aluminium 7, iron 5, calcium 3, magnesium 2, sodium 2, potassium 2. Other elements which, though present in relatively small quantities, are widely diffused and of considerable importance, are hydrogen, carbon, nitrogen, phosphorus, sulphur, chlorine. Only six of all the elements mentioned occur in the free state—namely, carbon, oxygen, nitrogen, sulphur, hydrogen, and iron, the last two only in very small quantity

92. Origin of Soil.—There are many agencies at work in the formation of soils, and the processes of soil-growth are in continuous operation. All soil-material is formed by the breaking down of rocks, and soils may be divided into two classes. (1) sedentary soils, formed from the underlying rock, (2) transported soils, which after their formation have been carried into their present position by water, ice, or wind A sedentary soil has many of the characters of the rock below it, but is usually darker in colour, owing to the presence of organic matter or to exposure to the air, or to both causes. Between soil and rock there is an intermediate layer, the subsoil, consisting of partly broken-down rock and differing from the soil in texture, composition, and colour

Most rocks consist of fragments or crystals held together by cementing material or by interlocking The texture is seldom so close as to make the rock impervious to water, even the most close-grained granite or the finest marble will absorb water The chief agents that cause the "weathering" or breaking-up of rocks and the formation of soil are rain, changes of temperature, frost, the air, earthworms, and the roots of plants

Rain-water in falling through the air dissolves a certain amount of oxygen and carbon dioxide, which help it in dissolving minerals in rocks. The oxygen oxidises some of the rock substances—*e g.* rocks containing iron have a red colour due to iron oxide The carbon dioxide gives the water an acid action so that it can dissolve carbonates and some other substances insoluble in water alone. The mechanical effect of water in wearing down rocks is well known, soft rocks like clays and sandstones are often broken up merely by the beating of rain on their surface, and even the hardest rocks may be worn down by running water, especially when it carries sand or mud in suspension Besides the direct action of water, there is the action of water under the influence of frost If water is in the crevices of a rock when freezing occurs, its expansion pushes asunder masses of rock, and the same action breaks up rock-fragments and further pulverises the soil itself.

Apart from freezing, mere change in temperature tends to break up rocks, especially when the change is large and rapid The sun's heat during the day expands rocks, and the rapid radiation of heat after sunset causes them to cool and contract. The effect of these alternate expansions and contractions is to crack the rock and loosen the particles on the surface, and the effect is increased by the fact that the different minerals in rocks do not expand and contract equally Even in this country one often notices a difference of about 30° C, and sometimes more, between the temperature during the day and the minimum temperature at night.

The air helps in breaking up rocks in two ways (1) chemically, by its oxygen uniting with other substances and producing softer materials; (2) mechanically, by the wind carrying dust and wearing down rocks, and also causing rain to beat on rock surfaces

93. Sedentary and Transported Soils—As a rule the rocks from which a soil is derived are found on digging down, but sometimes the soil-materials have been derived from distant rocks by the action of running water, wind, and ice-sheets.

(1) Sedentary soils, in which the products of weathering remain where they are formed, only occur where the surface is fairly horizontal or where plants are growing The latter prevent the broken-up material from being quickly carried away by rain, and also by their growth assist in the further breaking-up of the rock. Sedentary soils are chalky, sandy, or clayey, according as the underlying rock was limestone, sandstone, or clay These form the three chief types of soil, but there are of course gradations from one to the other In the case of limestone, water containing carbon dioxide often dissolves away the lime and magnesia, leaving the less soluble portions of the rock to form the soil These portions are usually clay and fine sand, so that a soil formed in this way is often clayey, and may contain less lime than other soils not derived from limestone.

(2) The mud carried by every stream after rain is an example of soil in the process of transportation Another is seen in the way rain washes soil from hill-sides, or from sloping fields (the cultivation of soil helps the action of water in this case, since the surface is repeatedly disturbed by ploughing, etc) Notice the difference in level of the soil surface when a hedge runs across a slope, the soil carried down the slope is stopped by the hedge or fence, and is gradually piled up against its upper side, while at the lower side the soil is usually carried away, leaving the hedge or fence higher above the surface. In books on Physical Geography you will find accounts of the formation of deltas, alluvial plains, etc., by rivers, also of the action of glaciers and ice-sheets.

94. The Nature of Soil.—Dry soil consists chiefly of small fragments of rock of various kinds, usually with varying amounts of organic matter derived from the breaking down of plant and animal tissue. This organic matter, or *humus*, can be removed from the soil by burning it. The soil-grains are coated with substances which have been dissolved in the soil-water, and have been deposited when the water evaporated.

95. Mechanical Analysis of Soil.—The amount of humus in soil is easily ascertained by drying the soil, weighing, then burning the soil thoroughly on a clean shovel or in a porcelain crucible and weighing again. The *texture* of soil is ascertained most readily by the use of sieves. The finest particles (silt-clay) pass through a sieve with 0.05 mm. mesh, and by means of a second sieve with 1 mm. mesh we can separate the residue into sand (passing through) and gravel (remaining on sieve). The structure of the soil is then expressed in percentages, *e.g.* gravel 10 per cent., sand 20 per cent., silt-clay 70 per cent.

Dry some soil by spreading it out on paper and exposing it to the sun in a dry place; weigh out 100 grammes of the dried soil, stir it up in a dish with hot water, transfer to a fine sieve (0.5 mm. mesh), and wash the finer particles through with the help of a camel-hair brush and then with a stream of water. The residue, or "soil skeleton," is then dried and weighed.

By using a series of sieves we can divide the "skeleton" into (1) coarse gravel, left on sieve with 4 mm. mesh, (2) medium gravel, left on 2.5 mm. sieve, (3) fine gravel, left on 1 mm. sieve, (4) coarse sand, the residue which passes through the 1 mm. sieve.

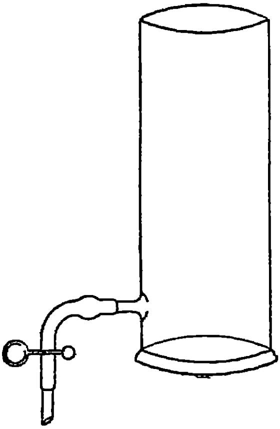

Fig. 29.—Washing Cylinder.

The fine soil, which passed through the 0.5 mm. sieve, is now separated, by washing, into clay-particles and fine sand; we know the weight of this fine soil, so we need not dry it. Pour it into a washing-cylinder (Fig. 29), a glass vessel 30 cms. high and 9 cms. in diameter, with a hole near the bottom into which a bent tube is fitted, passing through a cork and having a piece of rubber-tubing attached with a clip. The liquid is stirred up, the turbid water run off after about ten minutes, and the vessel filled again with water. These operations are repeated until all the **clay** seems to have been run off, and the residue of **fine sand** left in the vessel is dried and weighed.

The following simple methods do not involve the use of a special washing-cylinder, or of a series of sieves.

(*a*) Get about a pound of garden soil, stir it up in water to form a paste; place this in a jar, fill the jar with water, cork it, shake well for a few minutes, then allow to stand till the soil settles to the bottom.

Examine the soil after it has settled; the coarser material at the bottom is *sand*, above this is finer material consisting chiefly of *clay* (the finer grains remain suspended in the water, making it cloudy), and on top of the water floats a little decomposed vegetable matter (*humus*)

(*b*) Place a pailful of water on a table and dip into it a piece of rubber tubing, to act as a siphon Get a number of tumblers; into one place a handful of garden soil, and stir it up with water to form a thick paste Suck water through the tube to start the siphon-action, then direct a weak current (by pinching the tube) into the tumbler containing the soil, having a tumbler below to catch the overflow The weak current will carry over the finest grains. When the water runs clear, have another tumbler ready, and let a stronger current come through the tube Notice the time which the grains of different sizes take to settle and leave the water in each tumbler clear

96. Sand consists of grains of various sizes. Sandy soils are called "light" because they are easy to work, though a cubic foot of dry sand weighs about 110 lbs, while a cubic foot of dry clay weighs only 70 or 80 lbs, sandy soils are more open, more porous, warmer, and drier than clay soils A pure sand contains little but insoluble silica in the form of quartz-grains, hence it acts practically as a sterile medium, though when watered with dilute nutrient solutions plants are able to grow in it Sandy soils formed from crumbling rocks which have not been much washed by rain-water will, however, contain most of the elements necessary for the food of plants.

Sandy soils, which are too porous and have not sufficient cohesion for plants to get a good grip of them, are improved by any additions tending to greater consistency and retentiveness, such as the ploughing in of green crops, large quantities of farmyard manure, vegetable refuse of all kinds, powdered clay, black mud from the bottom of ponds, the cleanings of ditches, etc. Evaporation from sandy land during hot weather is largely checked by regular cultivation and the maintenance of a surface-mulch of loose soil an inch or two in depth, or by mulching with two or three inches of manure

97. Clay.—In clay the grains are smaller than most of those in sand, but they have a tendency to cling together and become cemented into composite grains. In drying, clay tends to form a hard compact mass, impenetrable by the roots of plants, when wet it tends to become sticky and waterlogged. Clay soils are said to be "cold" because they contain more water than sandy soils, but all good soils contain more or less clay, which is richer in plant-food than any other part of the soil. The presence of clay not only increases the power of retaining water, which is very deficient in pure sand, but also increases the percentage of phosphoric acid, potash, and magnesia.

Clay is also of great service to plants in "fixing" various substances essential for plant-food, that is, in combining with these substances and preventing them from being too readily washed out of the soil by rain-water. The presence of clay increases the power of retaining water, which is very deficient in sand, but this makes it difficult for a plant growing in a clayey soil to absorb enough water unless the soil contains a large amount In the latter case the soil is badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply

Pure clay consists of kaolin (silicate of alumina), but in ordinary clays the minute particles cemented together consist of quartz, felspar, or even carbonate of lime (in marls), as well as kaolin. The cementing material is a jelly like (colloidal) form of kaolin, which swells up on being wetted, making the clay sticky and impervious When pure clay is mixed with water, the muddy liquid produced shows practically no sign of depositing its suspended matter On adding mineral acids, or salts, or lime-water, the jelly-like clay is clotted (coagulated), and falls to the bottom Salts of lime are nearly as good as lime-water in causing this coagulation, while alkaline solutions—*e.g* soda or potash—favour the diffusion of the colloidal clay Lime is added to clay soils to improve their texture, clay-particles quickly settle when a river flows into the sea

Clay soils are very retentive of moisture and the useful products of manures, but are generally too firm, cold, and damp Such soils are improved by (1) good drainage, (2) additions of gritty sand, lime, ashes, burnt earth, long straw-containing manure and similar substances tending to increase the porosity of the soil, and (3) deep autumn trenching or tillage, involving the land being left in as rough and cloddy a state as possible for the winter, to secure the disintegration of its particles by the action of alternate freezing and thawing of the water with which its interstices are charged.

(*a*) Take two similar lamp-glasses, and to one end of each fasten with sealing-wax a piece of perforated zinc, to form a sieve; in each case place a piece of blotting-paper in the bottom, covering the zinc Take two equal quantities of dry clay, place one lot in one vessel as a coarse powder, moisten the other lot, and make it into a paste before pouring it into the other vessel. Fill up each vessel with water, and measure the volume of water which drains through in each case Another method is to use two funnels, each with a piece of perforated zinc covered with blotting-paper or filter paper

(*b*) Powder dry clay, then stir it up in hot water and pour it into two vessels (or test-tubes) To one vessel add lime-water, let both vessels stand, and note the result.

(*c*) Using the same apparatus as in (*a*), make a thin paste by working up clay or clayey soil with water, and pour an equal quantity of the paste into each vessel Fill one vessel up with water (distilled or rain-water if possible), the other with lime-water Note the time required for 50 c cs of liquid to percolate through the clay in each case

(*d*) Repeat (*c*), using (1) hydrochloric acid, (2) common salt, (3) caustic potash, in solution instead of lime-water.

(*e*) Pack clay or garden soil into a glass funnel, then pour in some ammonia-water, and place the funnel over a tumbler The water will, if the clay is packed tightly enough, come out at the bottom without any smell of ammonia The ammonia has been absorbed by the silicate of alumina present in the soil

(*f*) Repeat (*e*) with (1) dilute solution of caustic potash, (2) dilute solution of phosphoric acid In each case test the solution with litmus before adding it, and also test the water that comes out at the bottom

98 Limestone (carbonate of lime) may be present as soil-grains or merely as a cementing material to quartz-grains It supplies plant-food in the form of lime, magnesia, and phosphoric acid Its action on clay has been mentioned It also acts as a base with which acids, formed by decay of organic matter in the soil, can unite and thus be made harmless If such basic material is absent, the soil becomes "sour," through the accumulation of organic acids Even more important is the part played by carbonate of lime in the process by which certain Bacteria convert into nitric acid the nitrogen existing in organic matter or ammonia compounds, this process only occurs in a weakly alkaline solution, and the nitric acid unites with the lime

Calcareous soils, in which limestone or chalk predominates, are usually greyish in colour They readily harden and crack when warmed They are greatly improved by heavy dressings of decayed organic matter, nitrogenous substances, decomposed turf, and dark coloured soil rich in humus

99 Humus, the decaying organic matter of the soil, is of great importance both from its physical and chemical properties It is a light, bulky substance, with high specific heat, great capacity for holding water, and dark colour The presence of humus gives the soil a loose, open texture, and makes it able to absorb and retain water In woods, humus often accumulates to a considerable depth, but in ordinary soils it is only present to a depth of about a yard (below which the roots of few plants penetrate), and thus part of the soil has a looser texture and darker colour than the underlying subsoil, which contains no humus Humus contains from 4 to 9 per cent of nitrogen, far more than is present in the vegetable matter from which the humus is produced The conversion of vegetable matter into humus is largely caused by Bacteria and Moulds

100 Microscopic Examination of Soils.—Examine some sand, mounted in water, (*a*) in transmitted light with the mirror, (*b*) in reflected light without the mirror, sketch some of the grains Examine in the same way some clay, and try to distinguish between the grains of quartz (clear), felspar (cloudy), mica (brown), hornblende (black). Examine some leaf-mould, teased out in water, and make out the remains of leaves, twigs, roots, etc., and the fungus-threads which branch through the decaying vegetable matter

101. Classification of Soils.—The different kinds of soils may be grouped under certain generalised headings according to the amounts of chalk, sand, clay, and humus they contain **Loams** contain 40 to 70 per cent of clay mixed mainly with sand. If only from 10 to 40 per cent. of clay is present a *sandy loam* results, and below 10 per cent of clay the soil is merely *sandy* A loam containing 70 to 85 per cent of clay is a *clayey loam*, and above this is a *strong clay soil* The latter when containing up to 20 per cent. of chalk are termed **marl,** and if more than this they are termed *calcareous marls* Similarly we have *calcareous sand, gravelly loam, chalk loam,* etc, while any soil containing over 20 per cent of organic matter may be termed a humus soil independently of its other ingredients

102. Soil-Air.—The spaces left between the soil-grains form capillary tubes extending in all directions. These capillary spaces are occupied largely by air, if the soil is in good physical condition and not water-logged Great harm is done to plants by over-watering, house-plants are more often killed by this than by anything else, and plants in pots should be watered from below (why?) In general, the soil should not contain more than half its total water-holding capacity, *i e* about half of the capillary spaces in the soil should be occupied by air

The presence of air, containing oxygen, in the soil is obviously essential if healthy growth of seedlings and roots is to take place, moreover, the air in the soil must be kept in circulation. Good ventilation is as necessary for germinating seeds, and for the roots of plants, as it is for the life and health of human beings Not only is free oxygen in the soil required by germinating seeds and for roots, which must breathe, but many processes occur in the soil that depend on the presence of oxygen. Nitrogen is required for the use of Bacteria, which fix free nitrogen gas and make nitrates, and these Bacteria, as well as others which convert the nitrogen of humus, manure, and other decaying organic matter into nitric acid, require large amounts of oxygen in order to do this work

The exchanges of gases between soil and atmosphere are brought about in several ways—*e g* the slow process of diffusion; expansion and contraction of soil-air due to changes in temperature and in barometric pressure

The air contained in the soil is not enclosed, but is constantly being renewed by diffusion from the air above Since the processes going on in soil consist largely of oxidation, or are accompanied by oxidation, the soil-air is poorer in oxygen than the air above In general, the percentages of oxygen and carbon dioxide together equal 21, but that of oxygen varies from 10 to 20 per cent., that of carbon dioxide from 1 to 10 per cent

(*a*) To find out the best percentage of water and of air in the soil for any plant, take five tumblers filled with soil Add to A 16 c cs of water each day, to B, 8 c cs, to C, 4 c cs, to D, 2 c cs, to E, 1 c c Plant the same number of seeds (small seeds like Wheat or Cress are best) in each tumbler After a few weeks notice that those receiving too much water do not grow well because of lack of air in the soil, those receiving too little water will suffer from drought Select the tumbler which gives the best result, and find out how much *water* the soil contains by weighing a sample of the soil (after stirring it up), then drying it and weighing it again To find out how much *air* this soil contains, put the tube of a thistle-headed funnel to the bottom of the soil in the tumbler, and from a graduated vessel pour in water till it stands level with the surface of the soil Since the water displaces the air in the soil, we may consider the volume of water poured into the soil as representing roughly the volume of air it contained, compare this with the volume of the soil.

(*b*) Get two glass jars of the same inside diameter Pour water into one jar until it is rather less than half full, and mark its level Mark a corresponding level on the other jar, which is to be kept quite dry inside, and put dry soil into this jar until it reaches the mark We have now equal volumes of water and of soil Pour the soil slowly into the water, if the soil contains *no* air, it will make the level of the water rise to twice its original height, hence the amount by which it fails to do this measures the volume of air in the soil Try this simple experiment with different soils (sand, chalk, clay, loam), and find the percentage volume of air in each soil.

(*c*) Tie a piece of muslin over one end of a lamp-chimney, fill the chimney with soil, and set it in a basin. Pour water into the basin, and notice its rise in the soil Are the spaces between the soil-grains filled with air or with water at the beginning of the experiment? Try different soils, comparing the rise of water in them.

(*d*) Spread out some moist soil or fine gravel in a thin layer on a sheet of paper, notice the glistening appearance of the grains As the soil dries the grains become dull in appearance, why? In moist soil the water is in the form of films around the soil-grains, and the spaces between the grains are filled with air, only in quite wet soil are these spaces filled with water

103. Soil-Water.—Water occurs in soil under three conditions (1) *free water*, filling the spaces between the soil-grains and free to move under gravity and to trickle through the soil, (2) *capillary water*, adhering to the surfaces of the soil-grains and to plant-roots in films thick enough to allow surface tension to move it slowly from place to place, in any direction where the soil is becoming drier, (3) *hygroscopic water*, which is held around the soil-grains so firmly that it does not move about like the capillary water, and can only be removed by heating to 100° C, when it passes off as steam Even an "air-dry" soil retains a good deal of hygroscopic water The free water of the soil is injurious to plants (except those specially adapted—*e g* bog- or water-plants), because it interferes with the proper respiration of the root It is the object of drainage to remove it

104. Water-Content of Soils.—The amount of water present in the soil occupied by the roots is called the water-content of the habitat, or home, of the plant or plant-association The water-content of a habitat depends on the thickness of the water-films around the soil particles In saturated soils the films run together to form drops and masses of water, while in air-dry soil there is still a thin film around even the smallest soil particles Hardly any water is present in impervious rocks until cracks are formed by weathering, sandy fields or hills and other dry habitats have from 3 to 15 per cent, moist meadows, cultivated fields, and woods have from 15 to 30 per cent.; wet habitats, like stream-banks, are more or less saturated, their water-percentage varying from 30 to 80 per cent according to the texture of the soil

As we shall see later, the most important differences between the various habitats of plants are chiefly due to differences of water-content

105. Available and Non-available Soil-Water.—If a rooted plant is kept without water until it wilts and dies, we find that the soil still contains some water This non-available water, which the plant cannot use, is retained by the soil because the attraction of the soil-particles increases as the water-films get thinner, until it is greater than the attraction exerted by the root-hairs The amount of water thus held by the soil varies inversely as the size of the soil-particles, being largest in fine-grained soils like clay and smallest in coarse soils like sand and gravel The *greater* part of the total water-content is in any case available to plants, but it differs for different kinds of plants and is diminished by excessive amounts of salts in the soil and by low temperatures

The percentages of total water-content, available water, and non-available water per 100 grammes of dry soil are given approximately in the following table.—

	Sand	Loam.	Clay
Total Water-Content	18·5	52	68
Available Water	18	43	55
Non-available Water	0 5	9	13

106. How Water-Content is Influenced.—The most important factors which influence the water-content of a soil are (1) the nature of the soil, (2) the rainfall, (3) the humidity of the air, (4) the physiography of the habitat

(1) The amount of the water-content of a soil depends directly on its texture, which determines how much of the water falling on the surface shall run off, and how much of the entering water shall be held by the soil-particles, or drain away under the action of gravity, or rise again from the lower layers by capillarity and thus become available even for roots growing just below the surface

The finer the texture of the soil—*i.e* the smaller the grains and the narrower the spaces between them—the greater the depth from which water can be raised, the capillary rise of water is probably as much as 30 ft in a fine-grained soil—*e.g* clay loam. The amount of water evaporated from the surface and of that raised by capillarity is greatly increased by winds; capillary action is stronger in moist than in thoroughly dry soil, just as a cloth or sponge absorbs water more slowly when dry than when wetted The falling of rain on a dry soil will therefore cause the lower parts to become *drier*, while the surface layers will gain more water than that represented by the rainfall. The capillary rise of soil moisture is increased by rolling, which brings the upper soil into closer contact with that below.

The porosity of a soil is measured by the rate at which water passes *downwards* through it. Since the capillarity of soil varies inversely as its porosity, it is sufficient to measure the porosity. Sand is very porous, but has very little capillarity. Clay shows strong capillary action, but is very slightly porous. Porosity and capillarity are determined simply by using a cylinder of soil, and noting the rate of the downward or upward flow of water through it. By similar experiments we can compare the water-absorbing capacity of different soils and the rate of evaporation from them.

(2) Water-content depends absolutely upon rainfall, except, of course, in habitats with a constant water-supply owing to the presence of springs, streams, ponds, or other bodies of water. The soil becomes saturated after heavy rain, and its water-content gradually decreases through a dry period. Snow is often of importance, since it acts as a cover, preventing evaporation, and enters the soil on melting.

(3) Humidity is of great importance as the chief stimulus which controls the loss of water by transpiration. It is influenced by temperature, wind, air-pressure, altitude, and exposure, as well as by the water-content of the soil and the presence or absence of a covering of dead or living vegetation. Heat increases the capacity of the air for moisture and therefore lowers the relative humidity. Dry winds and high winds remove the humid air around plants, and keep the humidity low. Air-pressure affects humidity by varying the density of the air, and therefore its power of holding moisture.

The relatively small daily barometric changes, which constitute "weather," are of little importance except in their relation to rainfall, but the permanently low pressure at high altitudes increases evaporation owing to the rarefaction of the air. Exposure to sun and to prevailing winds, as seen on slopes, has a great influence on humidity; slopes with a southern exposure receive most light, heat, and wind, and are therefore drier than slopes facing northwards.

A dense covering of vegetation on a slope prevents rain-water from running off before it can be absorbed, besides hindering the washing away of soil; the cover also increases humidity by reducing the influence of temperature and wind on evaporation, and a cover of living plants keeps the air moist by the evaporation of water from the plants.

(4) The chief physiographic factors of a habitat are altitude, exposure, and slope. The two former act indirectly on the water-content, by their influence on humidity, which has just been discussed. The chief direct effect of slope is in controlling the amount of water which runs off and that which enters the soil, the amount of rainfall lost by run-off increasing with the angle of the slope.

107. To compare the **absorption of water by different kinds of soil,** take 100 grammes of gravel, sand, rich loam (good garden or field soil), leaf-mould, and dry, powdered leaves, and put each sample into a wide tube—*e.g.* a lamp-chimney—closed at the lower end by a bored cork; a glass funnel will do instead. Hold each tube or funnel in turn over a tumbler, and pour into it a litre of water; then measure the water that runs out at the bottom in each case. Which sample absorbs and retains most water, and therefore allows least water to run through? In an experiment like this, the weight in grammes of the water absorbed by 100 grammes of each dry sample was: gravel, 5; coarse sand, 10; fine sand, 30; barren sandy soil, 35; clay, 55; rich loam, 70; leaf-mould, 220; leaves, 500. These results show clearly that the water-absorbing capacity of soils is greatly increased by the presence of vegetable matter.

108. To compare the **evaporation of water from different kinds of soil,** take 10 tumblers and fill them to within an inch of the top with the following materials: 1, gravel; 2, sand; 3, sandy soil; 4, 5, 6, loam (garden soil); 7, gravel, covered by an inch of sand, with an inch of loam on top; 8, loam covered by an inch of powdered leaf-mould; 9, powdered leaf-mould; 10, water. The materials in tumblers 1 to 9 should be well dried, then an equal amount of water poured into each. Keep the loam in 5 loose at the top by stirring it to a depth of about an inch, and, after adding the water to it, place on the surface an inch of dry, sifted soil. Stir the loam in 6 thoroughly after adding water, and notice that the loam dries in hard lumps after this treatment. Weigh each of the tumblers, and place them together in a position out of direct sunlight. Weigh each day, and record the loss of weight of each due to evaporation of water.

109. Composition of Soil-Water.—Soil-water contains various dissolved substances—*e.g.* carbonate of lime; phosphate of lime; sodium chloride (common salt); magnesium sulphate (Epsom salt); sulphate of lime (gypsum); silicates of lime, etc.; nitrate of potash (saltpetre); compounds of iron, etc.

It has been calculated that no less than 100 tons of mineral matter is annually removed in solution from every square mile of English country. About half of this amount is limestone.

Since there is much diversity in the character and solubility of the rock into which rain-water penetrates, varying as it does from granite and gneiss to limestone and clay, it follows that the material dissolved must also differ considerably in kind and quantity. Scotland, north of a line joining the mouths of the Clyde and Tay, consists chiefly of hard crystalline rock, and the river water of this region contains less dissolved material than any other in the British Isles Much of the water of North Wales too is almost as free, for similar reasons. England affords a great contrast Its rounded limestone hills are easily worn away by water, which is rendered acid by the carbon dioxide it has previously dissolved. The gas expelled in bubbles when ordinary water is heated consists partly of carbon dioxide, which was dissolved out of the atmosphere

110. How Soil Temperature is Influenced. — The specific heats of different kinds of soil differ considerably The following list gives the approximate number of heat-units (Art. 57) required to raise 100 lbs of dry soil from 0° C to 1° C. · Peat, 30 , humus, 25 , chalk, 20 ; sandy humus, loam, pure clay and sand, each about 15 It is clear that much more heat is required to raise the temperature of water through 1° than that of the same weight of dry soil , hence a dry soil will warm in the sunshine more rapidly than a moist soil

A dark-coloured soil is warmer than a light soil, and shows a greater daily variation in temperature The degree of inclination of the surface and the direction of the slope often exert a marked influence on the temperature of the soil, and especially on its daily range. The effect of a south exposure is to make a difference of 2° or 3° C in the first foot or more at the surface. When the surface of the soil is very uneven, its heat is lost more rapidly in warming the air above it If the soil is loose and open in texture, the drier surface layer loses heat to the air, while the poor conducting capacity of the open soil prevents the heat from being conveyed deeply below the surface, and a lower temperature results. If the air is warmer than the soil, as often happens in spring, a large amount of heat may be conveyed rapidly into the soil with rain-water.

Except direct sunshine on the one hand, and direct radiation of heat away from the earth on the other, there is no factor which exerts so strong an influence on the temperature of the soil as the evaporation of water from its surface When a pint of water evaporates from a cubic foot of soil, it carries with it heat enough to lower the temperature of the soil considerably—if sandy soil about 20° C, if clay-loam about 15° C To dry saturated sandy soil till it contains half its maximum amount of water requires the evaporation of about 9 lbs to the square foot when the drying extends to the depth of a foot, the similar drying of clay-loam requires the evaporation of about 12 lbs of water It is largely owing to the latent heat of vaporisation of water and to the low specific heat of soil that a wet soil is cooler than the same soil when dry

When soil is rolled, its texture is made firmer, and it conducts heat better, so that the surface layers become warmer; the temperature at a depth of 2 ins may be about 5° C, at 4 ins about 3° C, higher than in entirely similar and adjacent but not rolled soil

111. Hedges.—It is important that the velocity of the wind close to the surface of the soil should be reduced Where fields are not sheltered by hedges, strong winds may sweep away the young crops, together with the upper few inches of surface soil—*i e* the best part of the soil Hedges also lessen the rate of evaporation of water from the soil. The drying effect of wind at 300 ft to the leeward of a hedge is sometimes 50 per cent greater than at 20 ft Since evaporation of water leaves the soil colder, the temperature will be higher close to the hedge than away from it At the top of a hedge-bank the light is feeble and the soil dry, but lower down there is more moisture and more light If the hedge has level ground on one or both sides, the differences in the amount of water at the base of the hedge and farther from it are less pronounced than when it grows from a raised bank with a ditch on each side

112. Daily Observations.—Besides observing the temperatures required for various germinating seeds in field and garden, you should find out the temperature of various kinds of soil at different depths (say at 3, 6, 12, and 24 ins. from the surface), and record the average temperature (for each plot of soil and for each depth) during each month of the year. Also take thermometer readings throughout the year on the two sides of a hedge, at top and bottom of a slope, in ditches, streams, and ponds, and compare these carefully Also keep a daily record of observations on humidity, rainfall, direction and force of the wind, barometric pressure, and temperature Compare all these observations, see how they are connected, or "co-ordinated," with each other, and try to find out their bearing upon plant-life

QUESTIONS ON CHAPTER II.

1. What relation exists between (*a*) inches and centimetres, (*b*) ounces and grammes, (*c*) pints and litres?

2. What is meant by (*a*) boiling-point, (*b*) freezing-point? How would you convert thermometer-readings from degrees Centigrade into degrees Fahrenheit, and *vice versa*?

3. What is meant by (*a*) "diffusion of liquids," (*b*) "osmosis"?

4. What is meant by "capillary attraction"? Why does water rise higher in a narrow tube than in a wider one?

5. What is meant by (*a*) "specific heat," (*b*) "latent heat"? What is the importance to plant life of the fact that water has high specific and latent heats?

6. How could you prove, by simple experiments, that air is necessary for germination?

7. How could you prove by experiments that air has weight and that it exerts pressure? Explain the construction of a barometer

8. What are the effects of changes of pressure and of temperature on the volume of air? How are winds caused?

9. State the composition of air, and the chief properties of its two main constituents.

10. How could you detect the presence of (*a*) water vapour, (*b*) carbon dioxide, in the air?

11. How could you prove that a germinating seed respires (breathes), just as a living animal or a human being does?

12. How could you prove that germination does not occur in the absence of oxygen?

13 Why do seedlings grow badly in soil that is too liberally watered? How could you measure and compare the amount of air in different samples of soil?

14 Why should seeds not be planted very deep, nor merely laid on the surface of the soil?

15 How could you prove that warmth is required for germination, and how could you find, roughly, the best (optimum) temperature for germination in the case of some particular plant? What is meant by (*a*) the minimum, (*b*) the maximum, germination-temperature of a plant?

16 In what different ways is the temperature of the soil influenced?

17 Explain the construction of a Maximum and Minimum Thermometer. Why is a thermometer of this kind often used by nurserymen?

18 Explain the construction of a Black-bulb Thermometer What is its advantage over an ordinary mercury or alcohol thermometer?

19 What are the important points to attend to in taking barometer-readings, with reference to the weather?

20 What is meant by "relative humidity"? How does the use of a Wet- and Dry-bulb instrument enable us to form a rough idea of the changes in humidity of the air?

21 Describe the chief agencies by which soil is formed What are the differences between "sedentary" soils and "transported" soils?

22 What are the chief constituents of ordinary soil, and how may they be separated?

23 Describe the characters of sand, clay, limestone (chalk), and humus, with reference to the growth of plants.

24 Draw up a general classification of soils

25 How do the chief soil-constituents differ as to capillarity, ability to retain water, and usefulness as sources of plant-food?

26 What substances are found dissolved in soil-water? Describe the three conditions in which soil-water exists? Why is excess of free soil-water injurious?

27. How does soil-air usually differ from that in the atmosphere?

CHAPTER III.

SEEDS AND SEEDLINGS

113. The Germination of the Seed.—We have seen that the Broad Bean seed contains a young plant and is covered by a seed-coat, that the young plant consists of an axis which bears at one end (radicle end) a root-cap, at the other end (plumule end) some young foliage-leaves, and at the middle a pair of large seed-leaves, that when the dry seed is placed in water it swells up, that when the soaked seed is planted in moist sawdust or soil the seed-coat breaks open; that the radicle end of the young plant then grows down into the sawdust or soil and forms the root, and the plumule end grows upwards into the air and forms the shoot, while the seed-leaves remain in their original position, that the young shoot keeps for a time the hooked form which it has while inside the seed-coat, but gradually straightens out as it grows upwards, and that the young plant or seedling which arises in this way gradually grows into a mature plant

The changes that occur, from the time the dry seed is placed in water until the young plant establishes itself, are all included in the term *germination* The young plant in the dry seed is alive but dormant ("asleep"), and the germination of the seed is simply the awakening of the young plant to active life and growth

Broad Bean seeds (and those of most other plants) germinate best when sown within a year of their ripening; the longer seeds are kept the fewer will germinate and the feebler will be the growth of the resulting plants. Broad Bean seeds will sometimes germinate after being kept for six years In other plants the seeds may remain alive for a longer time, but the embryo, though dormant, is *living* and therefore gradually losing substance by respiration, besides losing water to the dry air around it.

114 Germination Jars —Into a large wide-mouthed glass jar put a rolled-up piece of blotting-paper, then fill up the jar with sawdust,[1] keeping the paper pressed against the glass. Place seeds in different positions between paper and glass (Fig 30), and pour in water enough to moisten sawdust and paper Fit up a few of these jars, because later on you will have seeds of several kinds to germinate

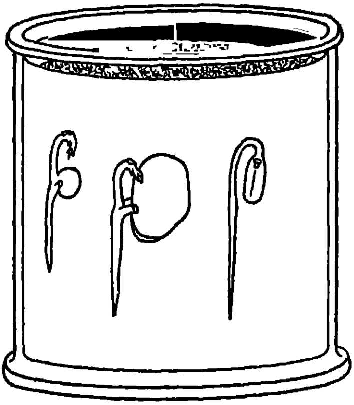

Fig 30 —Germination Jar The seeds (Pea, Broad Bean, Sunflower) have had the seed-coat and one Cotyledon removed

* **115. Glass-sided Boxes.** — Get two oblong wooden boxes (depth should be at least a foot for the long roots of Bean seedlings)

(*a*) Remove one of the longer sides and replace it by a vertical sheet of glass, at each end of the box fasten a strip of wood on each side of the glass, or simply knock tacks in to keep the glass side in position

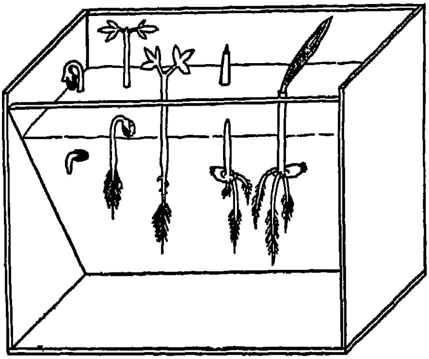

Fig. 31 —Glass-sided Germination Box, with Seedlings of Cress and Wheat

* (*b*) Make a similar box, but fix the glass side so that it slopes downwards and inwards (Fig 31)

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[1] Sphagnum (bog-moss) is better than sawdust, it is easier and cleaner to use, and it retains water better Tumblers or lamp glasses may be used instead of large glass jars.

* See footnote on p 71.

116. Early Stages of Germination.—In your germination jars and boxes place (1) dry seeds, (2) seeds that have lain in water for two days Which of these germinate the more rapidly, other things being equal? How do the young root and the young shoot emerge from the seed-coat? Which is the first to appear on the outside? Notice the V-shaped split in the coat along the edge of the root-pocket, caused by the root swelling up and raising the outer wall of the pocket as a triangular flap (does the apex of the triangle reach as far as the opening[1] in the seed-coat or not?) Watch carefully the way in which the stalk of each cotyledon grows in length, pushing the cotyledons apart and allowing the curved shoot to grow out between them For how long does the young

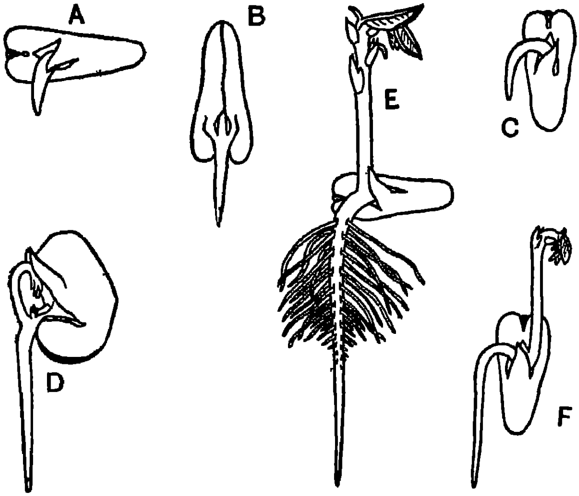

Fig 32.—Stages in Germination of Broad Bean Seeds, planted in various positions

root keep the lead as regards rate of growth in length? What is the advantage to the young plant in the fact that the root emerges before the young shoot? What advantage is there in the hooked form of the young shoot?

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[1] The erroneous statement that the radicle grows out through the micropyle in germination is often made in books This opening in the seed-coat doubtless helps the swelling radicle to split the coat, since it forms a weak spot, but a glance at a Broad Bean seedling shows that the coat splits along the edge of the radicle-pocket, the line of weakness, and that the split does not reach as far as the micropyle

* **117. Make Sketches** (in this case twice the natural size will be large enough, or even natural size if you have acquired a neat style in drawing) of (1) entire seed from the scar end, (2) same from the front, *i.e.* thicker edge, showing the pore and the bulge caused by the root, (3) same in side view, (4) side view showing the triangular flap being pushed off by the growing root, (5) front view showing the same, (6) side and (7) front views of embryo after removing seed-coat, (8) scar-end portion of empty seed-coat, showing the pocket into which the root fits, (9) side and (10) front views of embryo with one seed-leaf broken off, (11) section through whole (soaked) seed, to show pocket with root fitting into it (cut between seed-leaves) Also sketch various stages in germination of seeds planted in different positions and at different depths in your jars and boxes

118. What things are needed to make the seed germinate?—What have been the surroundings of the seeds whose germination you have been studying? Write down these things as they occur to you The seeds were first steeped in **water,** which they absorbed freely, becoming larger and softer, they were then placed in **soil** (or sawdust), they have been exposed to **light,** supplied with a certain amount of **warmth**, and lastly (though most obvious of all) they have grown in the **air.**

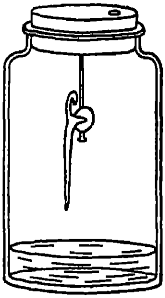

Fig 88

119. Is Soil needed for Germination?—Now, which of these things are absolutely essential for germination? Do you know of any plants which do not grow in the soil, but float on water? Examine the Duckweed plants, so common in ponds; their roots hang down in the water.

* Can you devise a simple experiment to show that a seed can germinate in the air, without any soil or sawdust for the root to grow into? In what condition would the air have to be kept during the experiment? Get a wide-mouthed glass jar and pour into it enough water to cover the bottom to a depth of an inch or so Then stick a long pin

through a soaked Broad Bean seed and fix it into a cork (or a piece of wood to cover the mouth of the jar), inverting the latter so as to bring the seed into the jar (Fig 33). The seed will germinate in the moist air Keep this simple piece of apparatus for later experiments.

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* Throughout this book asterisks are used to indicate a course of experiments which are of fundamental importance.

120. Is Water needed for Germination?—Will a seed germinate if kept dry? Place some dry seeds in dry sawdust and others in moist sawdust (an inch below the surface), compare the results after a week or two

Are seeds able to absorb water from moist air? Can they absorb enough in this way to enable them to germinate? Fold up a piece of zinc gauze to form an open box and suspend it by threads from the lower side of a cork bung (or a wooden cover), so that it can hang down into a wide jar containing some water. Weigh some dry seeds, put them into a gauze box, do not let them come into contact with the water Weigh the seeds again from day to day, to see whether they have absorbed water from the moist air in the jar. Why do seeds germinate or become mouldy when kept in a damp cupboard?

121. How to dry Seeds, Seedlings, etc.—Are the "dry" seeds sold by the seedsman quite dry, or do they contain any water at all? Into a dry test-tube (warm the tube all over to make sure it is quite dry) put a "dry" seed and heat over a Bunsen or spirit-lamp, applying the flame to the bottom of the test-tube Notice the drops of water which condense in the colder upper part of the tube With a dry knife cut a dry seed into pieces, or crush it in a mortar, and notice that the water is driven off more quickly than when a whole seed is heated, why? Cut 20 dry seeds into pieces, weigh these, and then dry them thoroughly without scorching or charring them at all This is best done by placing the seeds for a few hours in an oven, or by means of a sand-bath or a water-bath Then compare the weight of the thoroughly dried pieces and find out the percentage weight of water which the "dry" seeds originally contained (usually about 10 per cent). This amount of water, though not sufficient to allow of germination taking place, is evidently necessary for the seed to remain alive and capable of germinating The weight found after thorough drying, without charring, is called the **dry-weight** of the seed or seedling

* To dry seeds, seedlings, leaves, etc, without charring them, use a slow oven, a water-bath, or a sand-bath over a small flame A simple water-bath consists of two tin cups and an iron tripod to rest them on; half fill one cup with water, and into it put the other cup containing the seeds to be dried As an alternative, use a saucepan for the water and a saucer for the seeds to be dried. A simple sand-bath consists of a shallow tin or pan filled with sand, supported on a tripod and heated below as usual, the seeds being placed in a smaller tin or a saucer resting on the sand. Unless you have a good drying-oven, you will find the sand-bath just described very useful, the simple water-bath

described has drawbacks, for the lower cup must be filled up as the water boils away, and the water-vapour given off may reach the seeds in the upper cup

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* See footnote on p 71

122. Absorption of Water by Seeds.—In the absorption or imbibition of water by dry seeds we have an interesting subject for investigation Imbibition is due to the attraction of the particles (molecules) of the two substances for each other, which partly overcomes the cohesion of the molecules of the imbibing substance, making them separate so that the substance swells. The swelling is most marked in resting or dead tissues Imbibition makes the tissues more porous by separating the molecules and is thus an important aid to osmosis (Art. 50)—the process which controls the diffusion of liquids through membranes Imbibition is increased by warmth and by the presence of dilute acids and alkalis, but is diminished by that of salts The work done in imbibition is shown by the force exerted by swelling seeds or wood, and by the fact that heat is given off

(*a*) Keep some "dry" seeds in a drying-oven or drying-bath until they show no further loss in weight, and then find out whether they swell up in water and whether they germinate The results will show that killed seeds still have the property of absorbing water What other dead substances have this property? By what methods, besides thorough drying, could you kill seeds? Try boiling them in water or steeping them for a few days in poisonous liquids—*e g* alcohol, acids, caustic potash

* (*b*) When a dry seed is placed in water, how much does it absorb, and what proportion do the volume and weight of the absorbed water bear to the volume of the dry seed? Weigh twenty dry Beans, pour water into a graduated vessel until it reaches the 150 c c mark, then drop in the beans, and shake the vessel to get rid of any air present, the rise in level gives the volume of the Beans Take them out and place them in moist sawdust for two days, then wipe them dry, weigh them, and find their volume as before If you have no graduated vessels, use a glass jar with a strip of paper, marked into inches or centimetres, gummed on the outside of the jar Beans absorb 130 per cent. of their own dry weight of water, or even more than this; Wheat and Sunflower seeds absorb about 60 per cent, Red Clover seeds 100 per cent

* (*c*) The swelling of seeds by imbibition of water can be easily demonstrated to a class Put about 30 grammes of dry Peas and an equal amount of water into a narrow cylindrical glass jar Cover the Peas with a cork which will just fit the jar; smear the edges of the cork so that it can slide inside the jar, and pass a thermometer through a hole

bored in its centre Weigh the cork down with lumps of lead or a number of weights and mark its position by gumming a strip of paper on the outside of the jar Fit up a "control" experiment in which a cork with a thermometer hangs into a jar containing some water but no seeds

Note the rise of the cork as the Peas swell and push it up, and compare the temperatures, at the beginning and end of the experiment, in the jar containing the Peas and that containing water (or that of the surrounding air)

(*d*) Saw cubical pieces of (1) hard wood, (2) soft wood, (3) dry wood, (4) fresh living wood, measure their sides carefully, record your measurements, and calculate the volume in each case Set the pieces in water and after they have soaked for a day or two take them out and measure again Which swells the more, hard wood or soft wood, dry wood or fresh wood?

(*e*) Does imbibition cause rise of temperature in dead substances as well as in seeds? Put some powdered starch into a tumbler, to form a layer about an inch deep, put an equal amount of water into another tumbler, and set a thermometer into each When the two temperatures are equal, pour the water over the starch, stir with the thermometer, and note the rise in temperature (how many degrees?)

* (*f*) If a small wooden box (*e g* a cigar-box with the lid fastened down by tacks) is filled with dried Peas and then immersed in water, it will burst as the Peas absorb water and swell Try this experiment A large mass of swelling Peas may lift a weight of more than 100 lbs

(*g*) The force exerted by swelling seeds can also be shown by filling an ordinary narrow-necked bottle with Peas, and placing it under water in a basin, the bottle should be left uncorked, and some rubber bands should be put round it to prevent the shattered glass from being thrown out Another method is to fill with dry Peas an empty rabbit-skull and let it lie in water, the bones will be torn apart along the seams (sutures) where they join each other.

* (*h*) How is the absorption of water by seeds affected by temperature? Weigh about 30 grammes of dry Beans or Peas, place them in a beaker of water at 35° C, set the beaker on a sand bath with a thermometer in the water, and keep the temperature steady at 35° C for two hours At the same time place an equal weight of seeds in cool water, with a thermometer, first let the water stand for a time till it acquires the temperature of the room At the end of two hours, wipe dry both lots of seeds and compare the increase in weight in each case The seeds that have been kept in water at 35° C. will have absorbed from two to three times as much as those kept in the cool water

* (*i*) Weigh about 30 grammes of dry Peas and place them in a 10 per cent solution of salt in a beaker or tumbler. At the same time put a similar weight of Peas in distilled water (or tap water). Compare the weights of the two lots of seeds after two hours, wiping them dry before weighing Which lot has increased most in weight?

123. Where does Water enter the Seed?—When dry Beans or Peas are placed in boiling water, air escapes from the micropyle; sometimes air-bubbles also come from the scar. When a dry seed is placed in water or moist sawdust or soil, does the water enter solely by the micropyle, or partly by the scar, or does any enter by the rest of the seed-coat?

* (*a*) In a box of moist sand, which must be kept moist by adding water every day, plant three rows of Beans, those in the first row with the scar end downwards, those in the second with the scar end upwards, those in the third laid flat with the scar at one side. Press them into the sand so that each seed is half buried, and compare the germination of the seeds in the three rows.

(*b*) Weigh a number of dry Beans and fix them into notches cut round half the circumference of a flat cork; about half of each seed should dip into the water, with the scar end downwards. Weigh an equal number of seeds and fix them into the rest of the edge of the cork, but with the scar end upwards, well out of the water. After a few days, remove each lot of seeds separately, wipe them dry, weigh, and compare.

* (*c*) Could water enter by the scar if the micropyle itself were sealed up? Seal the micropyle in some dry seeds (weigh before and after sealing) with sealing-wax, plasticine, rubber solution (or tyre-mending cement); put the sealed seeds in water along with some unsealed dry seeds which have also been weighed. Try two other lots in which the sealing substance covers (1) the scar but not the micropyle, (2) both scar and micropyle. You should wipe dry and weigh the sealed and unsealed seeds at intervals, to find out which lot is absorbing water most rapidly and which most slowly. When unsealed seeds have absorbed the maximum amount of water (about 120 per cent for Broad Bean), seeds with sealed micropyle that have been in water for the same length of time will have absorbed only about 60 per cent.

124. How does Water enter the Seed?—If you put some dry Broad Bean seeds into a jar, fill the jar up with water, and let it stand open for a few days you will notice that the seeds swell up but do not germinate (the radicle may burst through the seed-coat), and a scum forms on the surface of the water, which after a time becomes cloudy and ill-smelling. The scum, cloudiness, and bad smell are due to the growth of "germs," or *bacteria*, which have evidently entered from the air, though some may have been present in the water (unless it was boiled for some time) or on the seeds (unless they were washed with formalin or other substance that kills germs). Bacteria can only grow in the presence of organic matter, hence the seeds have not merely absorbed water, but have also lost some organic matter, which has passed into the water around them This loss occurs even when the micropyle is sealed up with sealing-wax, rubber-cement, etc

In an experiment, 25 Broad Bean seeds were found to weigh 61·8 grammes; after being kept at 45° C in a drying oven for two hours they weighed 56 2 grammes, and as this weight was again found on weighing half an hour later it was taken as the actual dry-weight of the seeds The seeds were placed in water, which was renewed every day, and after five days the soaked seeds were dried at 45° C till they showed a steady weight of 51 3 grammes This means that nearly 10 per cent. of the solid matter of the seeds had diffused into the water

125. Capillarity and Osmosis in Seeds.—Water enters the seed partly by way of the pore (micropyle) and partly through the seed-coat The micropyle is a canal leading into the cavity of the seed, which draws water in by *capillarity* The water passes round the edge of the cotyledons, into the space between them, and into the radicle-pocket Water also enters by *osmosis* through the seed-coat, and at the same time part of the solid matter contained in the young plant passes out, in solution, into the water This substance which escapes from the seed is largely cane-sugar in the case of the Broad Bean When the cargo of a wheat-carrying ship becomes damaged by water on a voyage, the weight of the Wheat when dried again is found to have suffered considerable loss by sugar passing out into the water We shall see later how the Bean seed and Wheat grain come to contain sugar after soaking in water and beginning to germinate

126. Is Air required for Germination?—The seeds in your germination jars and boxes are exposed more or less freely to air It is very easy to find out whether air is essential for germination, by simply depriving the seeds of air.

* Drop some seeds into a glass jar or wide-necked bottle, fill up with water and cork tightly As a control, put some soaked seeds into a similar jar, leaving it open and adding a little water each day to prevent the seeds from becoming dry, but not enough to cover them Ordinary tap-water contains dissolved air, but as a rule seeds immersed in it, in a corked bottle, do not germinate, to make quite sure that no air reaches the seeds, the water should be previously boiled to expel the dissolved air, and the cork sealed air-tight with vaseline or plasticine To hold the seeds down, fix them into a spiral coil of wire, made by winding iron or brass wire round a tube or a stick

* **127.** *How much Air is Necessary to enable a Seed to Germinate?*—To answer this question, we may confine some seeds in closed vessels containing different quantities of air, and compare the results Take four glass jars, all of the same size, and provided with well-fitting corks (Fig 34) Fill these jars to different heights with moist sand, marking each jar into five equal parts, and putting into the first jar enough sand to reach the lowest mark; into the second, sand up to the next mark; and so on The fourth jar will thus contain four times as much sand, and therefore only a quarter as much air, as the first Into each jar now place six soaked Beans (or twenty Peas), cork tightly, and seal with plasticine and vaseline In which jar do the seeds germinate best? Do the results suggest that germinating seeds cause some change in the air, that they use the air up?

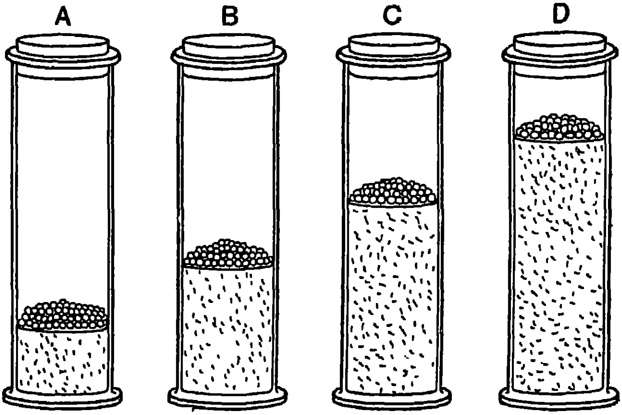

Fig 34.

After three or four days, carefully remove the cork from one of the jars and lower a lighted taper or match into it note what happens Open another of the jars, and dip into it a glass rod which has been dipped into clear lime-water (or baryta-water, made by shaking up some barium hydrate with water and filtering).

128. Respiration of Germinating Seeds.—These experiments show that germinating seeds absorb oxygen and give out carbon dioxide, so that a germinating seed changes the air around it in the same way that an animal does by its breathing Since the same change is produced by burning in air a candle (which contains carbon) or a piece of charcoal (which is practically pure carbon), we see that the respiration or breathing of a germinating seed, or of an animal, is simply a process of oxidation, a slow burning of carbon. Hence the seed must contain carbon in some form; we shall return to this point later. Meanwhile, here are some further experiments on the respiration of germinating seeds.

* (*a*) Get a wide-mouthed jar with a tightly fitting cork; bend a glass tube twice at right angles, so that the two parallel legs will be of about equal length, and through a hole in the cork push one of the legs until it nearly reaches the bottom of the jar (when corked). Fill a small muslin bag with soaked Peas, mixed with bits of soaked Sphagnum or clippings of wet sponge, and hang the bag to the lower side of the cork by means of a bent pin. Put a bit of sponge soaked in caustic potash solution[1] in a small wide-necked bottle or an egg cup and lower it into the jar (Fig. 35). Smear the top of the cork and the rim of the jar with plasticine. Put the outside tube in a tumbler or open bottle of water coloured with red ink; keep the apparatus in a fairly warm place, and note any visible result.

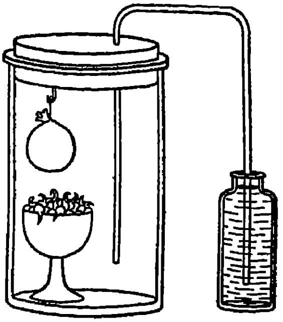
Fig. 35.

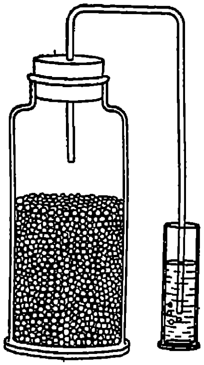
Fig. 36.

After a day or two, when you find that no more water seems to be collecting at the bottom of the jar, raise the cork and insert a lighted taper. Now write out an exact account of what has happened during this experiment. What changes in the air have been wrought by the germinating seeds? Why does the water pass over through the bent tube from the vessel outside into the jar?

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[1] This solution rapidly absorbs any carbon dioxide in its neighbourhood, but the carbonate of potash formed is *soluble*.

* (*b*) In the last experiment the carbon dioxide produced by the germinating seeds was absorbed by the caustic potash solution in the sponge Omit the latter this time, use the same jar (Fig 36), half-fill the jar with soaked Peas or Beans, and fix the bent tube so that the end of one limb is above the level of the seeds, while the outer limb dips into a bottle containing lime-water or baryta-water Set the apparatus in a warm place, and notice the bubbles of carbon dioxide which are given off, and which cause a white precipitate

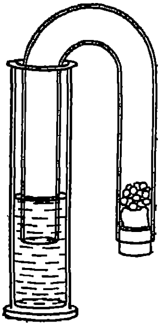

Fig 37

* (*c*) Take three U-tubes and three narrow jars (or test-tubes a little wider than the U-tubes). Place in one arm of each U-tube (Fig 16) six soaked seeds (Peas or Wheat), then invert the U-tube after inserting a cork, with a wad of soaked cotton-wool to keep the seeds moist Half-fill the jars or test-tubes with (1) water, (2) strong caustic potash solution, (3) strong solution of pyrogallol in caustic potash, and place the open ends of the U-tubes in the test-tubes If you have no suitable narrow jars, support the test-tubes in a stand

Notice that in (3) the solution soon rises in the inverted U-tube (how far does it rise, and why ?) and the seeds germinate very little (why ?), in (2) the solution rises, more slowly, and to the same extent (why ?), and the seeds germinate well, in (1) the water hardly rises at all, though germination occurs as in (2) What has happened in each case? In (2) the seeds absorb oxygen from the air and give out carbon dioxide, which is absorbed by the potash solution, and the latter therefore rises slowly in the U-tube for about a fifth of its length, in (3) the potash and pyrogallol solution absorb the oxygen of the air in the U-tube Why does the water not rise in (1) ?

129. Intra-molecular Respiration.—In the foregoing experiments it is clear that normal germination does not occur unless the seed is supplied with air containing oxygen. In some cases, however, a slight amount of growth occurs even when the seeds are deprived of oxygen, and sometimes a good deal of carbon dioxide is given off under such conditions This is easy to prove by the following experiments

* (*a*) Soak some Peas in water for a day, so that their coats can be removed without damaging the embryo (the coats are removed so as to avoid introducing air with the seeds) Fill a test-tube with mercury and invert it in a dish of mercury, then pass six peeled Peas under the open end of the tube, when they will float up to the closed end.

In a day or so the test-tube is half full of gas what is this gas, and how has it been produced? With a bent tube pass a little water under the test-tube, so that it will float up to the surface of the mercury, then pass up a small piece of caustic potash, the strong potash solution thus formed absorbs the gas, and the mercury rises again to its original position.

This production of carbon dioxide, in the absence of free oxygen, is called "intra molecular respiration", apparently in some way the substance of the embryo is decomposed in this process, and besides carbon dioxide, alcohol and other products are formed This "intra-molecular respiration" is very marked in Peas and Beans In all cases it is a process of destruction, without healthy growth taking place, it seems to be related to the process of alcoholic fermentation

* (*b*) Another method, good for demonstration to a class, is to use the "Torricellian vacuum" (Art 62) Pass a few peeled Peas into the vacuum at the top of a 33-inch tube filled with, and inverted over, mercury Test, after a day or two, with caustic potash as in the preceding experiment Note the height of the column (1) after the Peas are passed up, (2) after the column is depressed by the carbon dioxide formed, and (3) after the absorption of this gas by the caustic potash In each case note also the reading of the barometer at the time (why?)

In each case, as a control experiment, use Peas which have been killed by boiling in water is carbon dioxide produced by killed seeds?

Seedlings of Broad Bean, when kept in pure hydrogen, will for several hours give off as much carbon dioxide as in ordinary air, but in most plants the amount of this gas produced by intra-molecular respiration is much less (about half) than that given out in normal respiration

130. Heat produced by Respiration.—From the foregoing experiments it is clear that respiration is a process of oxidation, just as burning is, and this suggests that it may be accompanied by the giving out of heat Do germinating seeds give out heat?

(*a*) Fit three tumblers or jars with a cork or a cardboard cover, with a hole in the centre through which a thermometer is passed. First compare the readings of the three thermometers by placing them together in water at different temperatures. Half-fill one jar with soaked seeds (Peas, Beans, Wheat, or Barley answer well), the second with seeds that have been killed by boiling (add some corrosive sublimate to the water to prevent growth of moulds or Bacteria); the third with moist sawdust (as a control) Place the three jars, with thermometers inserted to equal depth in each, in a box, and put dry sawdust between and around them; cover the whole with a bell-jar or a dry cloth, and compare readings of thermometers at the start of the experiment and then at intervals of a few hours A rise of 2° C or more may be observed.

(*b*) Instead of jars or tumblers use three test-tubes, each with a bored cork for the thermometer, place the tubes horizontally in a cardboard box, with thermometer-stems projecting through holes, and pack round and between the tubes with dry cotton-wool

131. Where Air enters the Seed.—Does air enter the seed through the micropyle or through the seed-coat, or by both routes, as we found to be the case with the water required for germination?

(*a*) Soak seeds in water which has been previously boiled (why?), in two or three days they will absorb sufficient water to enable germination to begin Treat half of the soaked seeds as follows Wipe them dry, and close the micropyle of each seed with sealing-wax; place these seeds on moist sawdust Place the rest of the seeds, unsealed, on moist sawdust as a control In which lot of seeds does germination first occur?

(*b*) Does air enter through the seed-coat? Cut across a soaked seed and fix the upper half of the empty coat, by means of sealing-wax, to the end of a glass tube, making the joint quite air-tight (test by blowing through it into water) Fill the tube with water that has been boiled (to expel air), then invert the tube so that the open end dips into a jar or tumbler of water Does air pass through the seed-coat and appear at the top of the tube above the water?

132. Influence of Depth of Sowing on Germination.—In the lower as compared with the upper layers of the soil we find, as might be expected, less air, less circulation of air, and more water. How does the depth at which a seed is placed in the soil affect its germination?

* Plant seeds in your glass-sided box at different depths Put the seeds close to the glass, and (unless the glass has been fixed in with putty so as to be air-tight) put them near the middle of the glass. If the seed is buried too deeply it does not get enough air for healthy germination, and it is apt to be attacked by moulds

133. Warmth required for Germination.—When the temperature of the soil falls to 0° C. nearly all life-processes become dormant, and for most cultivated plants these processes do not begin until a temperature above 5° C has been reached. There is for all plants a certain range of temperature within which germination is most rapid and which ensures the highest percentage of plants from the seeds sown. The temperature below which germination does not occur is called the *minimum*, that above which there is no germination is the *maximum*, while the most favourable temperature is the *optimum*, these might be called respectively the *lowest, highest,* and *best* temperatures for germination In general, the temperatures at which the seeds of most cultivated plants (excluding, of course, hot-house plants) grow *best* in our climate lie between 18° C and 35° C, with an average about 24° C Here are some examples —

	Minimum °C	Maximum °C.	Optimum °C
Cress	2	28	21
Red Clover	6	28	21
Wheat	5	42	25
Turnip	7	42	27
Scarlet Runner	8	46	33
Maize	9	47	34

Wheat and mustard begin to germinate at 4° or 5° C, Scarlet Runner and Maize at 8° or 9° C., Vegetable Marrow (Pumpkin) at 13° C., and Cucumber at 16° C Here are the approximate optimum temperatures for germination of some common plants Barley, Pea, Sweet Pea, Phlox, 18° C , Cabbage, Carrot, Lettuce, Oats, Stock, Petunia, 21° C. ; Rye, Beet, 24° C ; Clovers, Tomato, Mignonette, Pansy, 27° C

(*a*) Place some soaked seeds in a glass jar and cover them with moist sawdust, plunge the jar into a box containing pieces of ice, which must be renewed as they melt The ice will last longer if the box containing it is set into a larger box, and the space between the two boxes is packed with dry sawdust (why ?)

(*b*) Another method is to use two boxes as in the preceding, but to place in the smaller box a single box of ice, with dry sawdust below and around it, place the seeds directly on the ice and cover them with dry sawdust, which will be kept moist by the melting ice.

* (*c*) In winter and spring the minimum temperature for germination should be determined for as many seeds as possible Into a large flower-pot or seed-pan put some bits of broken earthenware at bottom, and fill up the rest of the pot with sifted soil. Plant in the pot a few seeds of different kinds, and bury the bulb of a thermometer at the depth of the seeds, tying the thermometer stem to a stick thrust into the soil Sink the pot up to its rim in the soil of a garden bed and record the temperature each day, looking for any signs of germination. After two or three weeks bring the plants indoors, keep the soil moist; make notes of your observations Other pots should be kept in different parts of the house or school, in addition to those kept outside. Such experiments will show that warmth hastens germination, while cold retards it

134. Effects of Heat on Seeds.—When a seed is exposed for a few hours to a moderately high temperature, all the water it contained is driven off, and the young plant is killed. We can only tell whether a seed is alive or not by finding out whether it will germinate when exposed to suitable conditions

(*a*) Place in a small muslin bag a dry bean and a bean that has soaked for two days, and dip the bag into water which is boiling over a Bunsen or spirit-lamp Try several pairs of seeds in this way, keeping them in the boiling water for different times (1 minute, 2 minutes, etc.), then plant them in your germination jars or boxes, with a suitable label on the glass above or below each seed Find out in this way how dry and soaked seeds differ in their ability to withstand the effects of heat

(*b*) A better plan is to place the dry seeds in a dry test-tube, the soaked seeds in a test-tube half filled with water; cork both tubes, and immerse them in a beaker placed on a sand-bath and kept at 60° C for two hours (try several different temperatures and times) Then soak the dry seeds in water for a day or two and sow both lots.

135. Effects of Cold on Seeds.—We find that dry seeds can withstand high temperatures which are fatal to soaked seeds On placing seeds among ice or a freezing mixture we find that dry seeds can also resist *low* temperatures that kill soaked seeds It has been found that the dry seeds of many plants can germinate after being exposed for a long time to the most intense cold that can be obtained, while soaked seeds are usually killed by exposure to the freezing temperature of water or a few degrees below this.

(*a*) Repeat the preceding experiments (Art. 134), using a mixture of ice and salt instead of the hot water

* (*b*) Does the seed-coat help the seed to resist heat or cold? Repeat the preceding experiments, using and comparing complete seeds (dry and soaked) and similar seeds with the seed-coat removed.

136. Is Light required for Germination?—This question is very easy to answer by experiment

(*a*) Place in a dark cupboard or cellar some jars or boxes containing seeds planted in moist sawdust Compare with seeds of the same kind, planted and watered in the same way, but set in the light

(*b*) A better plan is to keep the two sets of seedlings close together; exclude the light from one lot by covering the jar or small pot in which the seeds are planted by inverting over it a large flower-pot or putting it into a tin or wooden box with a few holes for ventilation Compare the rate of growth of the two sets of seedlings from day to day, and note any other differences between them.

137. Light retards Growth.—These experiments will show that **light retards the growth of seedlings,** since they grow faster in the dark. You will also notice that the darkened seedlings have small pale leaves instead of well-developed green leaves, we shall deal with these differences later (Art 218)

138. Conditions necessary for Germination.—If you have carefully carried out the simple experiments on germination for which directions have been given, you will know what conditions are essential for germination of a seed which contains a live but dormant plantlet **Water, oxygen,** and sufficient **heat** are the three essentials for the awakening of the young plant from its sleep We shall see later that for the continued healthy growth of the plant other things are necessary, without which the seedling after a time dies

139. Growth in Light and in Darkness.—If you have carefully performed the simple experiments mentioned in Arts 127 and 128, you will see on reflection that the germinating seed must lose carbon in its respiration To measure this loss we must, of course, dry the seeds and seedlings before weighing them. Does this loss occur both in light and in darkness?

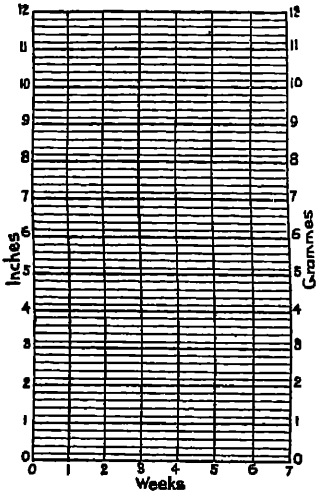

Fig 38.—Chart on which to plot the Curves of Height and Weight.

* (*a*) Take about forty Beans as nearly alike in size and weight as possible, select four of them as samples, and find their weight after thoroughly drying them on a water- or sand-bath or in a slow oven Take the dry weight of a seed, found in this way, as the average Sow half of the seeds in sifted garden soil in a box which is kept in darkness, the other half in a box kept in full light; water both lots about equally

At the end of each week measure and record the average height of the shoot in each lot of seedlings, remove three seedlings from each box, wash the roots in running water (do not leave any in the soil or lose them in any way), and dry them thoroughly without charring any part When quite dry and brittle, weigh each lot and obtain the average weight of the solid matter in each plant Get a piece of squared paper, as in Fig 38 (spaces *representing* inches need not, of course, be inches) As the weekly observations proceed, trace two lines across the sheet, one (a continuous line) to show the weight, the other (a dotted line) the height of the seedlings grown in light, draw two other lines in red ink to show the weight, and height, of the seedlings grown in darkness.

* (*b*) Another method is to use Wheat grains, and grow them with the roots in water From some Wheat count out thirty-six good sound grains, and divide them into batches of a dozen each, see that the weight of each batch is as nearly as possible the same Dry one batch (A) and record the dry weight Tie a piece of muslin over a tumbler or bowl filled with water, and put a batch (B) of seeds on the surface of the muslin, which should be kept wet Another plan is to use a piece of flannel, stab twelve holes in it, and in each hole place a seed Keep the tumbler in a warm, dark place, and renew the water every second or third day Plant the third batch (C) as in (B), and keep both at about the same temperature, but when the young shoots appear, expose (C) to the light When the shoots have grown several inches, carefully remove the seedlings from (B) and (C), noting the difference in colour between the two sets Dry them thoroughly, without charring even the finest rootlet, and then weigh each lot and compare the weights of (A), (B), and (C)

* **140. Growth in Soil and in Sawdust.**—Have you noticed any difference between Bean seedlings grown in *soil* and those grown in *sawdust*? If you sow the two lots of seeds at the same time, water both lots with equal quantities of tap-water, and keep them exposed to the same conditions as regards light and warmth, which lot will grow best? Try to find out by measuring heights and dry weights, as in the preceding experiments, and plotting the results in curves

141. The Bean Seed contains Food.—The results of these experiments will show that **while a seedling kept in darkness grows more in height, it loses in dry weight,** so that, apart from water, **it actually weighs less than the seed itself did**, and eventually it dies It is obvious that this loss must be largely due to respiration, and that it is chiefly a loss of carbon in the form of carbon dioxide. The seed must, therefore, contain a store of carbon in some form, and it is at the expense of this stored carbon that the darkened seedling respires and grows On the other hand, seedlings grown in the light after a time increase in dry weight, and are therefore able not only to repair the loss due to respiration, but are also able to add to their dry weight in some way

To repair the waste due to respiration and to provide material and energy for growth, the young plant in a seed requires a store of food upon which it can draw during the early stages of germination Where and in what form is this food stored, how is it made use of, and how does it compare with the store of food placed at the disposal of young animals—*e g* in eggs and in milk? From their size and thickness it is easy to infer that the cotyledons of Beans or Peas form the storehouses of reserve food-stuffs

* (*a*) Place a piece of Bean-cotyledon on the end of a long needle (a needle mounted in a piece of wood like a penholder is best for purposes like this), and hold it over the flame of a spirit-lamp, notice that it turns black in a few seconds Rub the charred mass on white paper, it leaves a black mark of charcoal (carbon) Continue to heat the piece for some minutes, and note that it burns to ash

* (*b*) Heat some dry Beans or Peas in a test-tube fitted with a bent tube passing through a bored cork, and dip the free end of the tube into lime-water or baryta-water. Notice the white precipitate produced by the carbon dioxide set free.

* (*c*) Crush, or cut up into small bits, some Beans or Peas, mix them with three or four times the quantity of soda-lime, and heat the mixture in a test-tube Fumes of ammonia are given off, proving the presence of *nitrogen*

To make soda-lime, mix two parts of quicklime with one of solid caustic soda and one of charcoal, moisten with water, mix into a paste, dry thoroughly, and keep the powdered mixture in a corked jar

142. Food stored in Bean Seed.—From these simple tests it appears that in addition to carbon the Bean seed contains nitrogenous substances and also some mineral matter (ash ingredients) The Bean seed contains all the chief kinds of human food—water, mineral salts, proteids, carbohydrates, and oil (scanty)—see Art. 185

143. Carbohydrates.—Starch and **sugar** both exist abundantly in plants, and are called carbohydrates, because on analysis the proportion by weight of hydrogen to oxygen found united with the carbon is always the same as exists in water—viz. 1 : 8 Starch is insoluble in cold water, but is easily converted, by various processes, into sugar, which is soluble Both starch and sugar resist change when exposed to air, and sugar is even used to preserve various foods from decomposition, as jams, crystallised fruits, etc A *weak solution* of sugar, however, exposed to the air is soon converted into one of alcohol, by the action of Yeast Other carbohydrates are the **celluloses, gums, inulin.**

* (*a*) Heat some dry laundry starch in a test-tube Note the condensation of water in the upper part of the tube This proves the presence of *hydrogen* and *oxygen* in starch (since water is composed of these elements) Note also that the starch soon begins to *blacken*, proving that it contains *carbon*, and at the same time dirty white fumes are evolved, having a pungent odour somewhat resembling that of burnt sugar Apply a light to the mouth of the test-tube—the fumes are *inflammable*; introduce a piece of moist blue litmus paper into it—the litmus becomes red, showing that the fumes are *acid* Introduce a glass rod, on the end of which is a drop of lime-water, into the test-tube The lime-water becomes milky, showing that *carbon dioxide* is one of the products of decomposition of starch This confirms the presence of carbon in starch (since carbon dioxide is a compound of carbon and oxygen) When all the volatile matter has been driven off, a black glistening residue of *charcoal* remains

* (*b*) Shake a very little starch in a test-tube of cold water and boil well; add a few drops of iodine solution a blue colour is formed. Boil the blue solution, and the blue colour disappears, to return on cooling

* (*c*) Boil a little starch with dilute sulphuric acid, and test a few drops of the solution from time to time for (1) starch, and (2) sugar The reactions of starch are gradually lost, and those of sugar appear instead

* (*d*) Examine specimens of cane, grape, fruit, and milk sugars (1) Taste them they are all sweet (2) Boil with a solution of caustic potash cane sugar does not colour the solution, but the others turn it brown (3) Add a little Rochelle salt (sodium potassium tartrate), then excess of caustic potash, and finally some copper sulphate solution [1] [The object of the Rochelle salt is to prevent the precipitation of cupric hydroxide by the action of potash on copper sulphate] Boil cane sugar only precipitates red cuprous oxide on long boiling, but the others give a precipitate at once (4) Add a solution of silver nitrate to which excess of ammonia has been added, and warm: the cane sugar only reduces the silver after long boiling ; the others do so very soon

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[1] This is called **Fehling's test.** Dissolve 35 grammes of copper sulphate in 200 c cs of water to make solution A To make solution B (to be kept in a separate bottle) dissolve 70 grammes of Rochelle salt in 200 c cs of 10 per cent. caustic potash solution Use equal volumes of solution A, solution B, and water.

(*e*) Boil some cane sugar with dilute sulphuric acid for ten minutes, and test with Fehling's solution, etc it now gives the same reactions as the other sugars

These properties of possessing a sweet taste and of turning caustic potash brown and reducing copper sulphate and silver nitrate, either at once or after previous boiling with dilute acids, are characteristic of the sugars

(*f*) Moisten a little starch with a few drops of dilute hydrochloric acid and heat gently in a dish The sticky mass obtained is *dextrin* or "*British gum*" This on boiling for some time becomes malt sugar

144. Proteids, or nitrogenous food-stuffs, composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and in some cases phosphorus, occur in both vegetable and animal tissue, though only plants can build them up from their elements They form the living substance (protoplasm) found in cells of plants and animals, in decaying they give off offensive smells **Albumin** occurs in white of egg, **myosin** in lean meat, **gluten** in flour, **casein** in milk and cheese, **legumin** in Peas and Beans See books on Human Physiology

145. Wheaten Flour, made from the grains (seeds) of Wheat, makes very convenient material to examine and test for starch and proteids.

* (*a*) Take a tablespoonful of wheaten flour and enclose it in a piece of muslin Hold it under a tap of gently running water and work the flour about by constant squeezing. Catch the whitened water as it flows away from the flour In a little time the water passes off clear Keep working it for a little longer time, then open the muslin and discover a mass of sticky material this is gluten Let the muddy water settle, then pour off the liquid and keep the sediment The sediment is starch ; it forms a large proportion of the flour.

* (*b*) Put a small bit of gluten on the end of a mounted needle, and hold it over the flame of a spirit-lamp , it burns, then turns black Rub the charred mass on white paper ; it leaves a mark of charcoal (carbon).

* (*c*) Mix a little of the gluten with soda-lime, place the mixture in a test-tube, and heat by means of a spirit-lamp As the gluten decomposes, ammoniacal fumes are given off, thus proving the presence of nitrogen in the gluten

(*d*) Put a little of the gluten into a test-tube containing a weak solution of caustic potash Shake well · the gluten dissolves

(*e*) Put another bit of gluten into a small quantity of strong nitric acid in a test-tube or watch-glass Heat Note the yellow coloration, which deepens to orange if ammonia solution be gradually added Add the ammonia solution very cautiously with a glass tube, as the action between the acid and the ammonia is a violent one.

(*f*) Place a little of the sticky gluten in a test-tube and warm it Notice that the heat causes it to solidify

* (*g*) Take a little of the milky liquid from the basin The milkiness is due to starch granules Boil it this makes it go clear Cool the clear liquid, and add a few drops of solution of iodine A deep blue colour proves the presence of starch Note that the blue colour disappears on heating

146. Oils.—Many plants store up food in the form of oil, the corresponding food-store in animals is fat An *oil* is a liquid which when dropped on glazed paper makes it translucent, a *fat* is a solid which when melted behaves in a similar manner Oils and fats are compounds made up of carbon, hydrogen, and oxygen, the oxygen present being insufficient to combine with all the hydrogen and form water Chemically they are compounds of "fatty" acids with glycerine Most vegetable oils are obtained from seeds, *e g mustard, sunflower, linseed, castor oil* Others are obtained from the stem, *e g oil of turpentine,* others from the leaves, *e g eucalyptus oil,* and others again from the flowers, *e g lavender oil,* or the fruits, *e g olive oil*

147. Oils in Seeds.—There are two main classes of vegetable oils—(1) *volatile, ethereal,* or *essential* oils, obtainable by distilling the leaves, etc, in which they occur, (2) *fixed* or *non-volatile* oils, obtained simply by pressing the seeds containing them. Oily seeds usually contain little or no starch, and *vice versâ*

* Remove the coats from dry seeds of Sunflower, Cress, Mustard, Castor Oil, fold the seeds in blotting-paper and crush between two flat stones and note the greasy stain produced, which dissolves in ether or alcohol The young plant in a "Brazil nut" is very rich in oil, as can be seen on cutting the "nut" across, after removing the shell the oil is made very evident if the knife be heated

148. Digestion of Reserve Food.—The foods stored up in seeds for the use of the young plants must be insoluble in water, and not able to diffuse through membranes (cell-walls) why? The reserve food in the Bean cotyledons must, however, when the seed germinates, travel from cell to cell through the cell-walls in order to reach the places where it is needed (radicle and plumule), and in order to do this the food must be changed into soluble and diffusible substances The food stored in a seed must, in fact, be *digested* before it can be used by the young root and shoot, and the process of digestion in a plant is essentially the same as in an animal. Find out all you can, from books on Physiology, about the digestion of starch, proteids, and fats In the germinating seed, just as in an animal, starch is converted into sugar, proteids into peptones, oils into fatty acids and glycerine (which are further changed into sugars, etc).

149. How is Starch digested?—In the human body the conversion of starch into sugar is partly effected by saliva (formed by glands which open into the mouth) and partly by the pancreatic juice (secreted into the part of the intestine just beyond the stomach) In both cases the change of starch into sugar is due to a substance, called a *ferment*, present in the secreted juice. A similar ferment occurs in plants, called *diastase*, the starch-converting ferments of animals get other names, but might be called *animal diastase*, to emphasise their essential similarity. Diastase occurs in germinating seeds in which starch is stored Starch is changed to grape-sugar by being made to unite with the elements of water, the action being called *hydrolysis* This can be brought about, as we have seen, by boiling starch in water for a long time, or more quickly by adding acid to the water

* (*a*) Boil some starch in water and put a little of the cooled paste on the tip of the tongue. After a time it tastes sweet ; some of the starch has been changed to sugar by the diastase (ptyalin) of the saliva

* (*b*) Mix a little starch paste (made with cold water) in a test-tube with saliva, warm it to body-temperature by holding the tube in the hand, or placing it in warm water, for a few minutes, then add Fehling's solution, and boil To get a fair quantity of saliva, chew a bit of rubber, filter the saliva

* (*c*) Add to some starch-paste a small quantity of filtered saliva which has been heated to boiling, after a while apply Fehling's test. No sugar is formed, the diastase has been destroyed by heating it.

* (*d*) Make a thick paste with flour and water, and mix with it some extract of malt The malt quickly liquefies the paste. Test for sugar in the liquid by tasting it, and by using Fehling's solution The first step in the process of brewing is to let Barley germinate until the starch is changed to sugar, the grain is then killed by heat, and a watery extract (malt) is made; yeast is then added, by the action of which the sugar is changed largely to alcohol, carbon dioxide being given off.

(e) Make thin starch-paste by shaking up a little ordinary starch or flour with boiling water and letting it stand to cool Get some seedlings of Bean or Pea in which the radicle has grown out at least an inch, remove the seed-coats, grind the cotyledons up with water, and filter through a funnel with filter paper or thin blotting-paper Pour the starch-paste into white saucers, putting a label on each Leave saucer 1 as it is, into 2 pour a few drops of iodine solution, into 3 pour some of the watery extract from the cotyledons. Set the three saucers in a fairly warm place, and after a time test 1 and 3 with iodine solution Notice that the starch-paste with the extract in it soon gives only a reddish colour with iodine, and ultimately remains uncoloured by iodine, showing that the starch has disappeared Taste the liquid in saucer 3 the starch has been converted into sugar by a substance (diastase) which has been extracted from the cotyledons (filter, and to the clear filtrate apply Fehling's test for sugar)

(*f*) Squeeze the milky contents of a few sprouting Wheat-grains into a test-tube or watch-glass with a little water, and stir Filter, add a few drops of Fehling's solution to the clear filtrate, and heat a brick-red precipitate or coloration indicates the presence of sugar

(*g*) Try Fehling's test with cotyledons of Bean seedling, also with the young shoot and root; chop up the parts to be tested

150. How are Proteids digested?—Proteids are acted on in the animal body by the gastric juice in the stomach and by the pancreatic juice in the small intestine; the former contains a ferment, *pepsin*, which acts only in acid solutions, the latter a ferment, *trypsin*, which acts only in neutral or alkaline solutions Germinating seeds contain a ferment resembling trypsin, which converts the proteids into soluble substances, including peptones Peptones differ from other proteids in being very soluble in water Pepsin is only found in a few plants, *e g* the pitcher-plant *Nepenthes*, but vegetable trypsins are of widespread occurrence, and some of them—*e g* papain —are now largely used in medicine The action of trypsin goes further than that of pepsin, the peptones being converted into simpler substances

(*a*) Get a fresh pig's stomach from the butcher's, cut it open, and wash it out. Next scrape off the inner coat with a blunt knife, and mince it up Put it into a mortar, and rub it up with some 2 per cent hydrochloric acid solution Leave it in a warm place for two hours Pour off the clear liquid, put it into some very small fragments of hard-boiled white of egg, and keep it at about the temperature of the body In less than an hour the white of egg (albumin) will probably have disappeared. It has been changed into peptone.

(*b*) Heat some of the liquid from (*a*), containing peptone, and notice that no clot is formed. peptone is not coagulated by heat (*c*) Get a fresh pig's sweetbread, chop it up finely, and put it to soak in a 1 per cent solution of sodium carbonate Pour off the clear liquid, and use part of it to show that it turns the starch into sugar Use the other part to show that it digests coagulated albumin

151. How are Oils digested?—In the human body the bile and the pancreatic juice act upon fats. They produce what is called "emulsification." This simply consists in breaking up the fat into tiny globules, which remain suspended in the liquid and do not run together again If oil is shaken up briskly with water it is broken up into globules, but these run together again on standing.

By first adding a little carbonate of soda to the water, and then shaking up with oil, a much more permanent effect is produced, and this milky fluid may be allowed to stand for some time without any of the oil running together again The emulsification of fats by the bile and the pancreatic juice is greatly aided by the *chemical change* that the pancreatic juice causes fats to undergo It splits the oil into glycerine and a fatty acid, the fatty acid unites with the alkalis that are present and forms a soap This power of changing fats into glycerine and soap (both of which are soluble in water) is due to the presence of a ferment called *lipase* (steapsin) in the pancreatic juice Lipase also occurs in seeds in which oil is stored.

(*a*) Pour a few drops of linseed oil into a test-tube, and add a little water (about 1 in deep) Place your thumb over the end of the test-tube, and shake the contents vigorously Note the appearance of the mixture, and put the test-tube in the stand for a quarter of an hour. It will then be noticed that the milky appearance has disappeared, and that the oil and the water have separated again into two distinct layers This is only temporary emulsification

(*b*) Repeat (*a*), but this time add a pinch of carbonate of soda to the water before shaking up The emulsification produced this time is of a much more permanent character

(*c*) Shake up some linseed oil with its own volume of 50 per cent alcohol (diluted methylated spirit) and test it with litmus papers · it is neutral Add to the mixture some Castor Oil seeds which have just begun to germinate (crush or chop them up), and test again with litmus after a few hours notice the acid reaction due to fatty acids

(*d*) Heat a little glycerine with small pieces of acid potassium sulphate for a few minutes note the sharp, pungent smell produced Test some of the liquid from (*c*) in the same way the characteristic smell (of acrolein) shows that glycerine is present Another test for glycerine is to add a few drops of copper sulphate solution and then potash solution; a deep blue colour is produced, but no precipitate.

152. How long does the Seed's Food last?—We shall see later that green plants get their food from two main sources, air and soil The young plant in a seed has a store of food for its early growth, a store which is sometimes very scanty and sometimes (as in Bean and Pea) very abundant We know that tap-water and even rain-water are not pure, but contain dissolved substances, while soil-water or river-water will be much richer in dissolved matter In order to find out how long the stored food lasts, we should therefore use *distilled* water, so that we know exactly what the roots have had at their disposal, we may use well-washed sand and water it with distilled water Seedlings whose roots grow in pure water do not live very long, as a rule, especially if they are kept in darkness, when their dry weight diminishes, and they die after using up the stored food In the light, however, the seedlings live longer, and for a time increase in dry weight

Bean and Pea seedlings exposed to light, with their roots in distilled water, grow for several months and may even produce flowers, though they are small and weakly as compared with seedlings grown in soil or in a culture solution Small seedlings, with scanty food-stores—*e g* Mustard—live only a few weeks when exposed to light and supplied with distilled water, and for a shorter time when kept in darkness

* (*a*) Deprive Beans and Peas of one or both cotyledons, and observe the result Remove the cotyledons, in different cases, (1) just after the seed has been soaked, (2) after the root has grown 2 ins long, (3) after the plumule has grown 2 ins long.

* (*b*) Grow various seeds in jars containing distilled water, fixing them either into holes in muslin or flannel, or into split or bored corks, fill up the water as required, but always use *distilled* water Keep some of them in darkness, expose others to the light, and compare their growth and their increase or decrease in dry weight Another method is to let the roots grow into sand that has been washed thoroughly with tap-water and then with distilled water, using the latter for watering

153. How is Food transported?—The foods produced by the action of ferments are soluble, and therefore able to travel to the places where they are needed, to supply material and energy for the growth of the young root and shoot It is easy to trace the passage of the digested foods, especially in the case of sugar, because whenever the sugar accumulaets some of it is usually changed back to starch, for a time at least

* In seedlings of Bean, Pea, and other plants you are growing, note that the root and shoot of the ungerminated seed as a rule contain no starch, but that after germination has begun starch appears in the young root and shoot, cut these parts longitudinally, and apply iodine solution to the cut surfaces

154. Energy furnished by Foods.—The amount of energy supplied by a food may be found by measuring the heat produced by burning it, and it is therefore called the *fuel value*. The fuel value of carbohydrates and proteids is about the same, that of fats is more than twice as great In plants, as in animals, the energy is obtained from the food by oxidation (= burning), and carbon is the principal substance burned, setting free carbon dioxide Burning 1 gramme of carbon sets free enough energy to raise 8 kilograms (= about 2 gallons) of water from 0° to 1° C, and about 2 litres (about 2 quarts) of carbon dioxide are given off. If all this energy were used in mechanical work, it would suffice to raise 3,400 kilograms through 1 metre (*i.e.* to raise more than 3 tons a yard high) The energy is used up by the plant in the form of heat and of chemical work, in addition to mechanical work

155. Emergence of Seedlings from the Soil.—You will have noticed the way in which the plumule of the Bean protects the young leaves from injury by bending backwards at the tip as it pushes its way upwards Seedlings can grow through hard and stiff soil, and in doing this the plumule must exert considerable force The shoot of a Broad Bean seedling can push upwards with a force of over a pound, and since its diameter behind the hooked part is about one-eighth of an inch, the force exerted = 80 lbs per square inch From the fact that the cotyledons of a Broad Bean of average size contain about a gramme of carbon, the seedling can get a large amount of energy by using the stored food

* (*a*) Plant some Beans about 3 ins deep in moist soil or sawdust in a flower-pot, and pack stiff clayey soil (or plasticine) firmly above them. Watch them to see whether they emerge at the sides or whether they push the whole mass of clay upwards

(*b*) Invert a short test-tube over a Bean seedling with a plumule about 3 ins long, then place over this a vertical glass tube open at both ends, inside which the test-tube can slide freely, and clamp this tube to a support. Into the upper end of the open tube place a second test-tube containing mercury or shot Mark with a paper strip the level of the top of the shoot, and see what weight of mercury or shot is required to prevent the shoot from continuing to grow upwards. Another method is to use a spring inside a closed tube in place of the mercury or shot, measure how much the force of the shoot, pushing up its tube, compresses the spring, then find what weight is needed to compress it to the same extent.

156. Other Seeds and Seedlings.—We still have several experiments to make with Broad Bean seedlings Therefore you should have seedlings ready in different stages of growth, besides making observations on those which you sowed in soil in pots or boxes, indoors as well as in the garden, the latter should by this time be in flower, or even in fruit

Now examine the seeds of a few other plants for comparison with those of the Broad Bean If you are really interested in Plant-life and have sufficient time, you should examine and germinate the seeds of all kinds of plants, both wild and cultivated This easy and interesting line of work is perhaps unrivalled as a means of gaining an insight into the physiology of plants, their adaptations, and their evolution

157. French Bean and Scarlet Runner.—First get some seeds of Dwarf French Bean (*Phaseolus vulgaris*) and of Scarlet Runner (*P multiflorus*). In both notice the position of the scar, the micropyle, made conspicuous by its raised margin, the wrinkling of the coat while the seed is soaking, the two very distinct foliage leaves of the young shoot, with the veins plainly visible; the small root-pocket inside the seed-coat Make sketches of the seeds and seedlings of these plants and compare with those of Broad Bean (Fig 39)

* Sow the seeds of these two plants and observe carefully what happens in germination In the Runner the cotyledons remain below the soil, as they do in Broad Bean, the cotyledons are in this case termed *hypogeal*. In the French Bean, however, the cotyledons are pushed upwards into the air, along with the young shoot, and are therefore termed *epigeal* How does this come about? Place seeds of the two kinds in your germination-jars or glass-sided boxes (Arts 114, 115) and watch their germination The best plan is to remove the seed-coat from the soaked seed, break off one cotyledon (as in Fig 39F), and place

within the glass the rest of the plantlet You should be able to find out for yourself that the carrying-up of the cotyledons in the French Bean is due to the growth of that portion of the young plant's axis which lies between the cotyledons and the root. From its position, this region is termed the *hypocotyl* (Greek *hypo* = below) The same thing occurs in many other plants—in the vast majority of plants, in fact, the cotyledons are epigeal In most cases, carried-up (epigeal) cotyledons are, or become, thin and expanded like typical foliage-leaves. Examples of this are afforded by Sunflower, Mustard, Cress, Sycamore, Lupin, etc In the different species of *Phaseolus* (Dwarf and Climbing French Beans, Runner Beans) we get a transition from the hypogeal to the epigeal type of seedling. Note the gradual shrivelling of the cotyledons in the Scarlet Runner seedling—to what is this shrivelling due ?

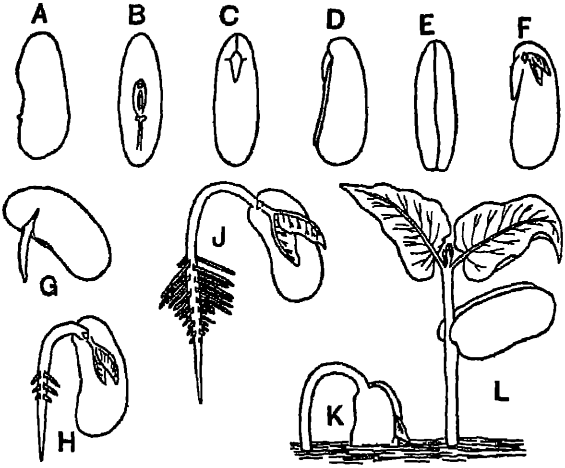

Fig 89 —French Bean A and B are views of the entire seed, C to F are views of the embryo (seed coat removed), G to L are stages in germination

You will notice that while the first two foliage-leaves are simple and heart-shaped and stand opposite each other, the later ones are compound, having three leaflets, and arise singly from the stem; what other differences can be observed? Notice the very regular arrangement of the side-roots in four rows on the main-root

Sow Scarlet Runner seeds in soil in pots and in garden border, so as to get flowering and fruiting plants for study later on Why is it considered necessary to sow the seeds of this plant near sticks or other supports ?

158. Garden Pea.—In the Garden or Eating Pea (*Pisum sativum*) notice that the transparent coat enables one to see clearly in the soaked seed the scar, the micropyle, and the root, all lying in the same line with the root-tip pointing to the micropyle The cotyledons remain below ground, and the earlier foliage-leaves resemble those of the Broad Bean seedling The later leaves are rather like those of Broad Bean, but the uppermost leaflets are developed as tendrils

159. Sweet Pea.—Get seeds of Sweet Pea (*Lathyrus odoratus*) and sow them in pots and in the garden In what respects do the seeds and the seedlings (*a*) resemble, (*b*) differ from, those of the Garden Pea? Why do Peas, like Runner Beans, need to have sticks or other supports placed near the young plants? For how long can they grow without supports? What happens if no sticks are placed near them?

160. Oak (Fig. 40) —In autumn get some ripe acorns, also unripe ones still attached to the "cup" Notice the circular patch at the broad end, how is this patch caused? Pull an acorn out of its cup, the patch is a *scar* What do you see at the narrow end? If you had examined very young acorns, you could tell at once that this end bore a tuft of three projections, which served to catch pollen and were the *stigmas* of the "female" flower Sometimes only the *style* which carried these stigmas remains on the ripe acorn as a short stiff outgrowth These facts show that the acorn is not a seed, but a *fruit* The hard coat is not the seed-coat, it corresponds to the shell of the Bean-pod.

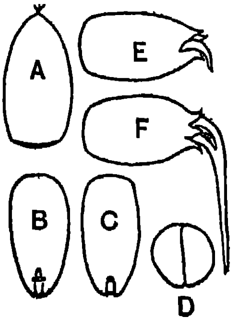

Fig. 40 —Germination of Oak.

Peel off the shell and notice the thin skin inside it, cut across the white contents of the acorn near the broad end and notice the line running across (Fig 40, D) Does the seed split readily into two lobes, as do the seeds of Beans and Peas? What does this splitting indicate? Pull the lobes apart and notice that one bears at its pointed end a conical pointed body, while the other shows in the corresponding place a groove, sometimes half of the pointed body remains on one lobe and half on the other. The appearance of this body suggests that it is the young root, while the two lobes are evidently cotyledons The young shoot is small, but quite visible

The acorn, therefore, contains a seed, consisting of a plantlet covered by a thin seed-coat It answers to a Bean-pod in which only one seed has ripened, one-seeded pods occur in Clovers, etc The acorn is an example of a one-seeded fruit;[1] such fruits are called *akenes* (or *achenes*) when they do not open to let the seed out

Soak ripe acorns and sow them Look for Oak-seedlings near the trees. Notice the splitting of the hard shell into several teeth at the narrow end, the emergence of the root, and the curious pushing-out of the young root and shoot by the elongation of the cotyledon-stalks, between which the shoot grows up. The earliest foliage-leaves have their edges even, or only slightly lobed, but otherwise resemble the later leaves The cotyledons gradually shrivel inside the split shell, do they contain food at first (test with iodine)?

161. Sycamore (Fig 41).—In autumn get some "keys" of the Sycamore Maple The keys are at first joined in pairs (sometimes threes) and each has a "wing" Watch the keys being blown from a Sycamore-tree on a windy day, noting their spinning or whirling movement through the air Does this movement carry them a long way from the tree? What causes the keys to whirl? Can you see how the whirling movement causes the "seed" to bore its way into soft moist soil? Throw keys into the air or drop them from a height, noticing how they fall (if calm) or are carried away (if windy). Repeat the experiments with keys from which the wing has been removed, compare the times taken for winged and wingless "seeds" to fall through the same distance.

If you have examined the green flowers of this tree, you will know that the keys are formed from the chambers of the ovary, each of which is produced into a flat outgrowth at the upper and outer edge, this outgrowth becomes the wing The two keys split apart when ripe, but for a time they dangle at the ends of a Y-shaped thread whose lower end is attached to the flower-stalk (Fig. 41, A, B).

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[1] Sometimes acorns have two or three seeds (occasionally as many as six) instead of one; this is easily seen when germination takes place and the roots of the young plants have grown out There may be as many as six seeds.

Open up the chamber of a ripe key and notice the brown-coated seed. Where is the seed-stalk attached, and what do you notice about the inside of the chamber? Carefully peel off the thin brown seed-coat and note the long curved root Evidently the young plant fills the whole seed, as in the Bean, while the key itself is, like the Acorn, an akene Sketch the young plant, then try to straighten out the long strap-like cotyledons (they will be less brittle if the seed is soaked in water), noting the peculiar and neat way in which they are folded and wrapped up. Try to find the small shoot-bud between the bases of the cotyledons.

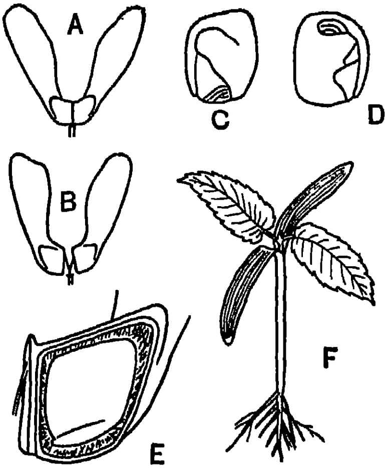

Fig 41 —Fruit (A, B), Seed (C, D, E), and Seedling (F) of Sycamore

Sow some keys and sketch stages in their germination. The root emerges from the side of the key where it split from the companion key, the cotyledons are carried up into the air and become straightened out The young shoot does not grow out so quickly as in the case of a Broad Bean or an Oak seedling, the cotyledons of the Sycamore do the work of foliage-leaves (to be studied later), whereas in Broad Bean and Oak the cotyledons serve as storehouses of food Carefully compare the Oak and the Sycamore with reference to the structure of the seed and its mode of germination, and think out the advantages and disadvantages of these two types of seedling.

As in the case of the Oak, you can at the right time of year (during which months?) get seedlings of the Sycamore, both near the trees and at considerable distances from them Notice that the earliest foliage-leaves are simpler in outline than the later ones (Fig. 41, F)

162. Sunflower (Fig 42) —Get "seeds" of this plant, and if possible Sunflower heads of different ages showing flowers and fruits In this case, as in Oak and Sycamore, the "seeds" are really dry one-seeded fruits (akenes) The Sunflower akene is attached to the plant by its narrow end (compare with Oak), and the hard shell is the fruit-coat; the upper parts of the flower fall off and leave only the fertilised ovary, *i.e.* the akene.

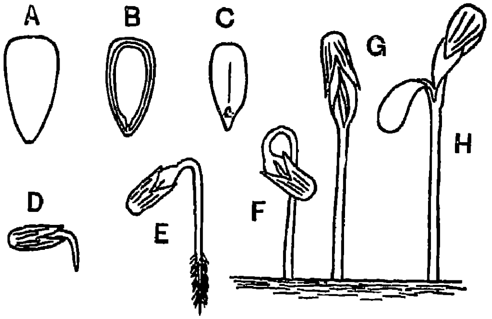

Fig 42.—Germination of Sunflower. A, entire akene; B, same with half of the shell removed, C, embryo with one cotyledon removed, E—H, stages in germination

Soak some akenes in water for a day or two and note that the shell splits along the edge into two pieces to let the root emerge from the pointed end The seed is attached by a short stalk to the pointed part of the akene; it has a thin coat and contains an embryo (note the two flat cotyledons, root, shoot) The cotyledons come above ground and turn green The stalk (hypocotyl) which carries them up is at first bent downwards at the top. This hook or loop is seen in very many seedlings, whether the cotyledons stay below or come up, in the former case it is the part above the cotyledons that is hooked, in the latter case it is the part below them (hypocotyl) Test the cut surface of a Sunflower cotyledon with iodine solution it gives a brown stain. No starch is present, the reserve-food consisting of oil and proteids, Sunflowers are grown in Russia, etc., for the oil in the seeds, used in making oilcake.

163. Maize (Fig 43) —Get some Maize "seeds," also a Maize "cob," from a corn-merchant The seeds of the "White Horsetooth" variety are much better for our purpose (because larger and more regular in shape) than the ordinary "Indian Corn" sold for poultry-food A glance at the cob, on whose axis the grains are crowded, shows that the narrow end of the grain is the fixed end, while the examination of a young cob shows that the thick end at first bears a long feathery outgrowth — the *stigma.* The ripe grain of Maize is therefore a one-seeded *fruit*, the stigma has fallen off and left no trace.

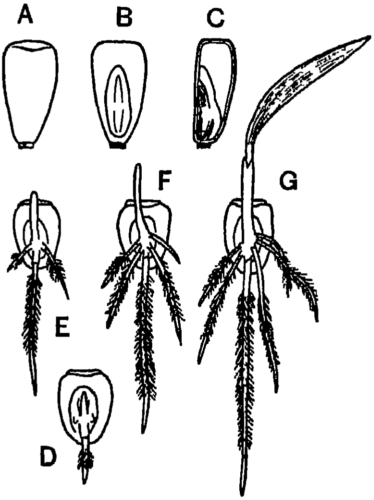

Fig 43 —Germination of Maize

On the outside of the grain, notice (1) the withered remains of the stalk at the narrow end, and (2) the oval patch on one side Examine the patch carefully, using several grains, and see if you can make out two ridges on it; one occupies the upper part of the patch (*i e* towards broad end of grain), the other the lower end, and both are in the same straight line drawn longitudinally through the middle of the patch (Fig 43, B).

With a knife catch at the pointed end of the grain and tear off the thin transparent tough skin Then try to learn something of the structure of this patch Are the two ridges caused by outgrowths from the patch? Try to raise them from the patch by putting the point of the knife-blade below each ridge. If you do this carefully you will see that these are two appendages which are fixed to the middle of the patch, the free end of one points upwards (*i.e* to broad end of grain), that of the other downwards. Perhaps this is all you can make out of the structure of these appendages at present

Does the oval patch itself lie on the surface of the grain, or does it project some distance into the inside of the grain? How can we determine its shape and position?

Lay a grain on the table with the patch-bearing side uppermost (choose a grain of regular shape) and make a clean slice down the middle of the patch If you have cut in the right way, you should see the two appendages plainly, attached to a fairly thick structure which projects deeply into the grain and runs across its interior (Fig 43, C)

With the knife-point, or a pin or needle, gently poke the two appendages about, you will find that the lower one is a solid peg, while the upper one separates into layers The upper appendage is the young **shoot**, bearing leaves, the lower one is the young **root**; this will be more apparent when you compare the seedling with the seed What is the shield-like oval body to which these appendages are attached? If you recall the appearance of a Bean embryo from which one of the cotyledons has been removed, you will probably conclude that this oval body is the cotyledon of the Maize embryo.

To see the shape of this "cotyledon" more clearly, try to remove the embryo from a well-soaked grain, by carefully scraping the convex surface and freeing this body from the rest of the grain, you will see its shield-like form more clearly. Some botanists prefer not to call this body (found in the grains of Grasses and Cereals) the cotyledon, it might be simply called the **shield.** What does the white inside of the grain suggest as to the probable nature of the stored food? If the shield, the root, and the shoot together make up the young plant, what is the *rest* of the seed?

Smear the cut surface (longitudinal section) with iodine solution This produces a vivid contrast between the young plant and the rest of the seed, the former is stained brown (proteid), the latter blue-black (starch), the two parts being separated by a sharp line. If the grain has been in water for some time, some starch will be present in the young plant how does this come about?

The starch-containing part of the Maize grain is something which is not represented in any of the seeds we have so far examined. It therefore deserves a special name, and it is called the **endosperm.** The Maize seed is said to be an *endospermic seed,* because in addition to the young plant present in all seeds it contains a tissue or region in which food is stored. Seeds which contain no endosperm, that is, nothing except a young plant, are therefore called *non-endospermic seeds, e.g* Beans, Peas, Oak In non-endospermic seeds the stored food is contained in the young plant itself, usually in the cotyledons.

When Maize germinates,[1] the young root appears first and grows vertically downwards. It bears rootlets, but it does not (as in Bean, Pea, etc) give rise to the whole root-system of the plant Examine and sketch seedlings of different ages; in one showing the first green foliage-leaf, study (1) **the root system,** (2) **the shoot system.**

(1) Note that two, three, or more roots have grown out from the base of the young shoot Examine the bases of the roots by means of a lens, and observe in each case the minute sheath out of which the root appears to grow, this sheath is

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[1] You will find that Maize germinates very slowly unless supplied with more warmth than most of the other seeds so far mentioned. Wheat germinates quickly, and might be used first.

produced by the newly formed root bursting through the tissue of the parent axis

(2) Observe the tubular sheath through the burst apex of which the first foliage-leaf has made its appearance Compare this with earlier stages of germination, especially noting that at first the sheath is closed at the tip, that for some time—certainly for so long as it remains under the soil—it grows at the same rate as the oldest leaf of the enclosed bud, but that sooner or later it gets burst by the rapidly elongating foliage leaf after the tip of the cone is carried well out into the air

Make a longitudinal section of the grain and the young shoot, taking care as nearly as possible to bisect the central axis of the embryo Observe that the "flour" or endosperm of the grain, especially in the neighbourhood of the developing plantlet, is reduced to a pulp The shield-like cotyledon remains in its original position and acts as a digesting and absorbing organ, it produces the ferment (diastase) that changes the starch stored in the endosperm-cells into sugar, which then must pass in solution through the cotyledon to reach the young root and young shoot This is easily observed, for whenever sugar accumulates in any part of a plant it is partly re-converted into starch The action begins as soon as the grain has absorbed water, and the iodine test shows that starch appears in the young plant In the "Sugar Maize" the conversion of starch into sugar begins before germination, so that the grain contains a good deal of sugar

164. Wheat resembles Maize in the general structure of the grain and the mode of germination, but there are several differences in details, which should be carefully noted.

In a soaked Wheat grain, note the deep furrow running along one side, the small projecting body (embryo) at one end of the opposite side, and the tuft of hairs at the other end Sketch each side of the grain With a needle remove the coat of the grain over the embryo, so as to see the radicle and plumule, behind which lies the shield-like cotyledon Slice the grain longitudinally, cutting down the groove, and sketch what you see (use a lens) Touch the cut surface with iodine solution the endosperm turns nearly black, the embryo brown With a needle raise the radicle and plumule from the cotyledon; in the plumule note the young leaves, which can be separated by using the needle

Sketch stages in germination, noting the arrangement of the foliage-leaves in two rows, their grass-like form, the parallel main veins joined by delicate transverse veins In a seedling showing the second green leaf, examine the root system and shoot system, as described for Maize Notice the shrunken appearance of the grain, which is now soft and pulpy Squeeze the grain and notice the milky or watery fluid which escapes, the milkiness is due to the presence of the minute starch grains Taste the fluid it contains sugar Examine some of it with the microscope, and notice that the grains are corroded and broken up while the starch is being converted into sugar Tear open the grain, wipe away the pulpy contents, and notice the white "shield" (cotyledon), which secretes the diastase required for the conversion of the starch into sugar and through which the sugar passes to the growing parts of the root and shoot systems See Fig 31 (Wheat on the right).

* **165 Further Work with Seeds and Seedlings** should be carried out as time permits Soak, dissect (remove coat, cut sections), and examine with lens as many different seeds as possible Test cut surfaces with (1) iodine solution for starch (blue) and proteids (brown), (2) a drop of strong sugar solution, followed by a drop of strong sulphuric acid (bright red colour = proteids), (3) nitric acid and ammonia (yellow colour = proteids). Practically all seeds contain proteids, together with starch or oils If the seed gives only a brown colour with iodine, showing the absence of starch, try the tests for oil (Art 147), and for cellulose (Art 171) Cut thin sections and examine them with the microscope In Maize and Wheat note the outermost layer of cubical cells in the endosperm, packed with proteid grains ("aleurone-grains"), also the layer of columnar cells (epithelium-layer) on the surface of the cotyledon, which secretes ferments

Sow the seeds in moist sawdust or soil, note the temperature required (or most favourable) for germination in each case; examine and sketch the seedlings from time to time In moistened seeds of Linseed, Cress, Turnip, Mustard, notice the jelly formed by the swelling of the gummy seed-coat when it absorbs water Small seeds—*e g.* Cress, Wheat—should be grown on muslin or flannel stretched over a tumbler filled with water, examine the roots for root-hairs and rootlets

* **166. Seeds with Food stored in Young Plant** —Examine the seeds and seedlings of Linseed, Cress, Mustard, Turnip, Radish, "Garden Nasturtium" (*Tropaeolum*), Horse-Chestnut, Vegetable Marrow, Melon,

In nearly all cases the cotyledons are carried up into the air by the lengthening of the hypocotyl In Horse-Chestnut the large cotyledons are partly fused together; notice that on germination the young stem and root are pushed out of the seed by the lengthening of the cotyledon stalks In Vegetable Marrow and Melon notice the method by which the seedling gets its cotyledons out of the cavity enclosed by the rigid walls of the flat seed, an outgrowth ("peg") is formed to hold down the lower half of the seed-coat against the soil, while the growing shoot raises the upper half of the seed-coat and thus gets free In Mustard the cotyledons are two-lobed, while in Cress (Fig 31) they are three-lobed In the "Nasturtium" (*Tropaeolum majus*) the later leaves have a nearly circular blade with even margin, and the stalk is inserted at the centre of the lower side of the blade, but in the earliest leaves of the seedling the leaf-blade is lobed and the stalk inserted at the lower margin, as in the adult leaves of the closely-allied leaves of the Canary Creeper (*T. canariense*).

167. Brazil "Nut."—In this seed the hard shell is the seed-coat; the minute cotyledons occupy the broader end of the embryo, the root being at the narrow end The greater part of the embryo consists of the swollen axis (hypocotyl), whose cells contain proteid and oil The two cotyledons and the plumule can be seen in a section examined with the microscope—if the section has been cut in exactly the right place

168. Endospermic Seeds.—In many seeds the stored food is not contained in any part of the young plant itself, but in a special part of the seed called the **endosperm,** which lies within the seed-coat but outside of the young plant (embryo). In some cases the endosperm surrounds the embryo (*e g* Castor Oil, Ash) In others the embryo is coiled around the endosperm, *e g*. Buckwheat. In all cases, however, the radicle of the embryo is close to the surface of the seed, just within the micropyle. In Maize, Wheat, and other Cereals and Grasses the embryo and endosperm are sharply separated by a plane drawn across the seed. Unfortunately the old term "albumen" is often used instead of endosperm, and this sometimes leads to confusion. Endospermic or "albuminous" seeds are seeds whose food is stored in a part *outside of the embryo,* and this food may be chiefly starch (*e.g.* Maize) or largely oil (*e g* Castor Oil), or cellulose in the form of much-thickened cell-walls (*e g* Date). The term "albuminous" does not, therefore, imply the presence of egg-albumin, though seeds *do* contain proteids, and exactly the same *kinds* of food are stored in endospermic and non-endospermic seeds alike.

*** 169 Castor Oil.**—Notice the spongy mass covering one end of the seed, the hard seed-coat, the oily endosperm, the embryo in the middle of the endosperm, with thin cotyledons pressed together (try to find root and shoot); cut longitudinal and transverse sections The spongy mass (aril) soaks up water; prove by placing seeds in hot water that this mass lies close to the micropyle See Fig. 44

*** 170. Ash.** — Steep the fruits ("keys") of Ash-tree in water, then cut open the fruit-cavity and notice the flat seed suspended at the end of a long stalk which runs along one edge of the seed Slice away one of the flat sides of the seed and expose the straight embryo, lying in the horny tissue (endosperm) filled with reserve food.

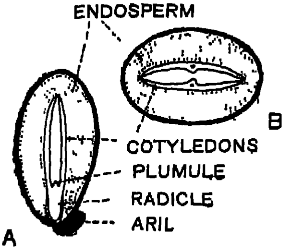

Fig 44 —Seed of Castor Oil

A, Longitudinal section, B, Transverse The dark outline represents the seed coat

*** 171. Date.**—Examine a Date seed (*i e* the "stone") Notice the deep groove along one side Scrape the surface on the other side, to see the small embryo embedded in the stone (endosperm) Cut the stone across at this point; then dip the stone in dilute sulphuric acid and apply iodine (test for cellulose) Plant some Date stones in damp sawdust or soil, set in a warm place (a heated greenhouse, if possible), and sketch stages in their germination Open the stone in some of the seedlings, and then notice the softening of the stone and the extent to which the cotyledon has grown inside it. Notice in sections of the stone that the cell-walls become thinner, and that starch appears in the young root and shoot, in darkness as well as in light The digestion (conversion into sugar) of the reserve food (cellulose) is due to the secretion of a ferment (cytase) by the cotyledon

*** 172. Onion.**—Examine a seedling of Onion before the embryo has finally withdrawn its cotyledon from the seed Observe (*a*) the long slender *root*, (*b*) the slight swelling at the base of the root marking the position of the relatively short *stem* from which arises (*c*) the long, hollow *cotyledon* whose tip is still within the seed-coat Remove the seed-coat and observe the colourless end of cotyledon coiled like a watch-spring within the seed. During germination the cotyledon absorbed the food from the endosperm and passed it on to the growing parts In older specimens observe how the air-exposed tip of the cotyledon withers, also note the formation of secondary roots from the base of the short stem, and slit open the hollow sheath at its base to see the delicate pale-green plumule within In still older specimens the plumule itself has split the sheath as a result of its growth,

* **173 Pine.**—In a Pine seed notice the thin wing, serving for wind-dispersal. Dissect the seed and notice the embryo (consisting of radicle, hypocotyl, and numerous cotyledons in a circle around the plumule) surrounded by the endosperm Sketch the stages in germination (Fig 45)

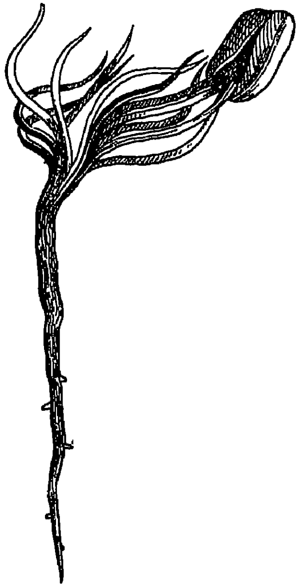

Fig. 45 —Seedling of Pine

174. The Uses of Cotyledons.—From the seedlings you have studied, you will observe that the cotyledons, or first-formed leaves of the young plant, have different functions or uses in different plants They are always concerned with the feeding of the young root and shoot, but they carry out this duty in different ways When the seed contains no food stored outside of the young plant, the cotyledons usually contain food In a few plants—*e g* Oak, Broad Bean, Pea—the cotyledons are food-stores and nothing more, they remain below the ground (or on the surface), and simply yield up the food to the growing root and shoot, and are termed "hypogeal" (= below ground)

In *most* non-endospermic plants, however, the cotyledons are carried up into the air and become green, and like all green leaves *manufacture* food (Ch V), even in these cases, where the cotyledons are "epigeal" (= above ground), they contain more or less food, though the amount is often scanty—*e.g.* Cress, Mustard—and they have a double function, first supplying stored food and then making fresh supplies. In seeds whose food is stored outside of the embryo, the cotyledons either remain within the seed and act as digesting and absorbing organs, as in Wheat, Maize, Date , or they first digest and absorb the food-store in the endosperm, and then emerge from the seed and become the first green leaves of the plant (Castor Oil, Ash, Onion, Pine)

Plants like Cress, Ash, etc , the embryos of which possess two seed-leaves, are classed under the name *Dicotyledons*, while Onion and Wheat represent the class *Monocotyledons*, as their embryos have only one cotyledon.

Make lists of the various seeds you have examined, arranging them according to (1) the presence or absence of endosperm , (2) the number of cotyledons in the embryo ; (3) the hypogeal or epigeal character of the cotyledons , and (4) the nature of the reserve food-substances

QUESTIONS ON CHAPTER III

1 How can you show that water is essential for the germination of a seed ? Why is the young plant in a seed said to be "dormant" ?

2 Give the results of experiments you have made as to the volume of water which a Broad Bean seed can absorb as compared with its own volume

3 How could you prove that a germinating seed respires (breathes), just as a living animal or a human being does ?

4 How could you prove that germination does not occur in the absence of oxygen ?

5 Why do seedlings grow badly in soil that is too liberally watered ? How could you measure and compare the amount of air in different samples of soil ?

6 Why should seeds not be planted very deep, nor merely laid on the surface of the soil ?

7 How could you prove that warmth is required for germination, and how could you find, roughly, the best (optimum) temperature for germination in the case of some particular plant ? What is meant by (*a*) the minimum, (*b*) the maximum, germination-temperature of a plant ?

8 What are the effects of darkness and of light on the germination of seeds ?

9 How could you prove that a germinating seed loses in weight when grown in darkness, that the loss is due largely to the oxidation (or burning) of carbon, and that the cotyledons contain carbon ?

10. Compare the food stored in a Bean seed with that supplied to young birds in eggs and to young mammals in milk

11 What is a carbohydrate ? Mention the chief carbohydrates, stating how they are distinguished from each other

12. What is a proteid? How do proteids differ from carbohydrates? By what simple tests could you detect the presence of a proteid?

13 How are oils and fats distinguished from carbohydrates and proteids?

14. How are the reserve food-substances present in a seed made available for the nourishment of the young plant?

15 What is meant by digestion? How are starch, proteids, and oils digested? To what extent are the processes of digestion similar in plants and animals?

16. How could you measure roughly the work done by a seedling in emerging from the soil? Where does the necessary energy come from?

17. What is the usual appearance of the top of the shoot of a young seedling, and what is the advantage of this? How do seedlings of Maize and Wheat differ from most other seedlings in this respect, and how do they emerge from the soil?

18 What is the difference in structure between endospermic ("albuminous") and non-endospermic ("ex-albuminous") seeds? Show that both kinds of seeds may contain the same kinds of food, and explain why the old terms "albuminous" and "ex-albuminous" often lead students into wrong ideas about seeds.

19. Describe, with sketches, the seed, the mode of germination, and the seedling of the following plants · Pea, Kidney Bean or Scarlet Runner, Oak, Ash, Wheat, Maize, Cress, Linseed, Sycamore, Onion, Cucumber or Gourd or Vegetable Marrow, Sunflower, Date, Pine, Horse Chestnut, Castor Oil plant, Mustard

20. Write an essay on the uses, and the behaviour during germination, of the cotyledons in the various seeds whose germination you have watched.

21. Enumerate the chief reserve materials of food which are stored in the seeds of plants Give an example of each, and explain how the embryo or seedling is enabled to utilise the food.

22. Explain why it is that certain seeds—for example, Peas and Beans—split readily when the testa is removed Name as many other such seeds as you can, and describe in some detail the germination of any one of them

23 Suppose you had two flourishing seedlings of the same size, and you grew one in the dark and the other in the light How would each differ from its original weight in the course of a few weeks? If one of them had gained considerably, how would you demonstrate exactly to what the increased weight was due? What other differences would you notice between them?

24. What are the chief points you would emphasise in a lesson on the germination of seeds? What material would you select for the practical work of the class?

25 What is respiration, and how is it affected (*a*) by heat, (*b*) by light, (*c*) by increased rapidity of growth?

Two lots of Peas, one of which had been soaked in water at 100° C, the other in water at 15° C, were passed into the vacua at the tops of two parallel tubes of mercury. How would the height of the mercury column be affected in each case? Would the after addition of caustic potash solution make any difference to the height of the columns?

26 Compare the seedlings of Sycamore and Lupin. Note the points of resemblance and difference

27 Describe a series of experiments by which you would illustrate to a class the chief properties of water in its three different states.

28 Describe and explain the mode of using Regnault's Hygrometer

29 Describe a wet- and dry-bulb thermometer, and state what inference can be drawn from its readings.

30. What are the practical difficulties in the way of germinating seeds in an ordinary class-room, and rearing the seedlings for some weeks? Show how these difficulties can be overcome.

31 What does milk look like under the microscope? To what substances does it owe its value as a food? Describe the result of heating to dryness until they burn, (*a*) a solution containing white of egg, (*b*) a solution containing cane sugar

32. Explain, with drawings, how certain seedlings withdraw their seed-leaves from the seed-coat

33 Mention two or three experiments on digestion which can be performed with very simple appliances in an ordinary schoolroom Give full practical instructions for one such experiment

34 Describe the seedlings of three plants in which the cotyledons have entirely different functions

35 Describe experiments of a chemical nature by which you could show (*a*) that starch is changed by the action of your saliva, and (*b*) that your expired air contains carbonic acid gas

36 Name the necessary conditions of germination, and describe experiments, which you have seen or performed, to prove what you say.

37. Describe exactly how you would obtain the dry weight of a seedling

What difference would you expect to find between the dry weight of (*a*) a seed, (*b*) a seedling of the same plant grown in the dark for some time, (*c*) a similar seedling grown under normal conditions for the same time?

Give reasons for your answer, explaining clearly the source or fate of the materials gained or lost.

CHAPTER IV.

THE MICROSCOPE AND CELL-STRUCTURE.

175. Microscope Work, if not allowed to occupy time which would (in the case of a beginner) be better spent in making physiological experiments and in studying flowers, fruits, plant-associations, etc., is valuable in helping one to understand more fully the life-processes and adaptations of plants, especially if minute structure is studied in close connection with physiology.

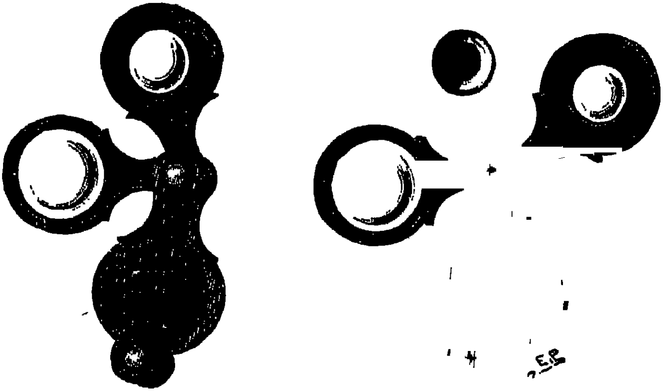

Fig 46.—Folding Pocket Lenses (Double and Triple).

176. Lenses.—The use of the simple lens has already been mentioned (Art. 4) A **double** or **triple folding lens** (Fig 46) is a great improvement on the simple lens, giving greater magnifying power when the lenses are used together. A lens of this kind is absolutely indispensable.

177. Simple Microscope (Fig. 47).—This consists of a stand, mounted on a heavy metal **base** and carrying (1) a glass plate or **stage** for the object to be examined, (2) a **lens carrier** in which the lens can be raised or lowered by a **rack-and-pinion adjustment**, (3) an **illuminator** below the stage with a mirror on one side and a white plate on the other.

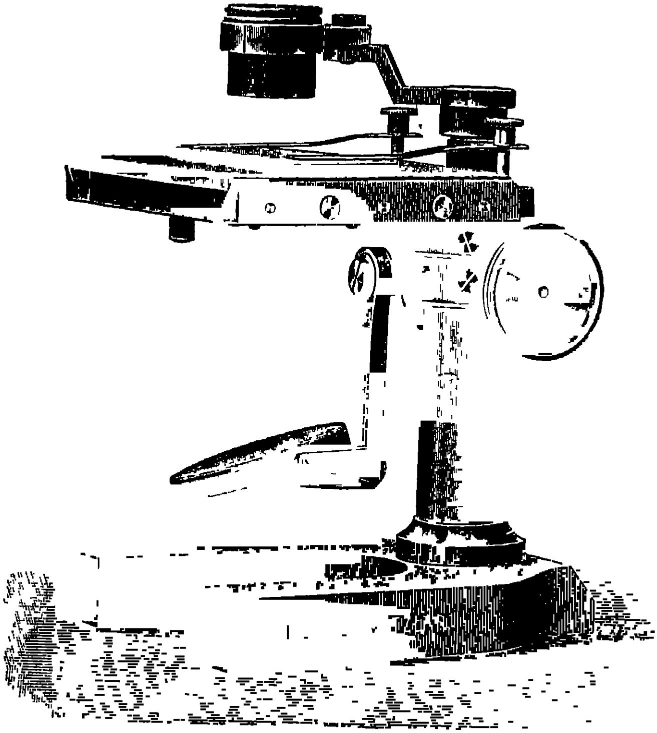

Fig. 47—Simple (Dissecting Stand) Microscope

The lens carrier can be moved from side to side, as well as up and down, the upper side of the stage has two **clips** for fixing down the object examined, if necessary, as when a mounted microscopic slide is used; below the stage a black metal plate or a milk-white glass plate can be inserted, serving as dark or white background respectively; and at each side of the stage metal, leather-covered **hand-rests** may be attached, to place one's wrists on when manipulating a specimen on the stage. A stand like this ("dissecting microscope") costs about £2, without the lenses.

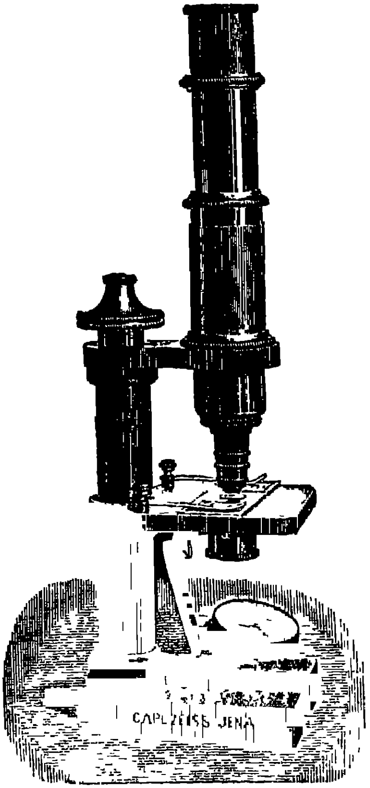

Fig. 48.—Compound Microscope with Sliding Coarse Adjustment.

178. Compound Microscope.—The simple microscope can be used for all purposes where a magnification of not more than 20 diameters is required, and is an extremely convenient instrument for this low-power work. When higher magnification is desired, we must use the compound microscope, in which the image of the object is obtained by one lens (or a set of lenses) called the **objective,** and this image is magnified by a second lens, the **eyepiece.** The objective is screwed into the lower end of the brass **body-tube,** which is blackened inside (why?); the objective consists usually of several lenses screwed together. The **eyepiece,** which magnifies the inverted image of the object produced by the objective, consists of two lenses, the one next the observer's eye being called the eye-glass and the lower one the field-glass

In the cheaper form (Fig 48) the tube which carries the lenses is moved up and down, to bring the objective near the object and thus bring the latter clearly into focus, inside another tube fixed to the stand, this is called the "sliding coarse adjustment" In the more expensive microscopes (Fig 49) there is a rack-and-pinion movement for raising or lowering the body-tube The **coarse adjustment** brings the outlines of the object dimly into focus, but to get more accurate focussing (especially when using a high-power objective) we use the **fine adjustment,** by turning a screw at the top of the stand, behind the body-tube

The object to be examined is placed on the stage, which has two clips for fixing a slide in a definite position, but these need not be used except for high powers, or while sketching There is usually a black plate, with holes of different sizes, under the stage, this can be rotated so as to bring the desired size of hole (*diaphragm*) under the central opening of the stage More expensive microscopes have an *iris diaphragm* A small hole is used with high power and a large one with low power

For ordinary work two objectives are required, one for low power (magnifying 60 to 80 diameters), and the other for high power (300 to 400 diameters). The most useful are 1 inch or $\frac{2}{3}$ inch low power objective and $\frac{1}{4}$ or $\frac{1}{6}$ inch high power objective Two eyepieces should also be used, the one with shorter body and narrower eye-glass is the more powerful

In most modern instruments the magnifying power can be increased by having the body-tube constructed like a telescope, the upper part (**draw-tube**), carrying the eyepiece, can be drawn out To avoid the inconvenience of having to screw and unscrew a lens every time a change of magnifying power is required, it is worth while to get a **nosepiece** (Fig. 50), which is screwed to the lower end of the body-tube; the nose-piece carries the two objectives, and by rotating it we can quickly change from low to high power and vice versâ

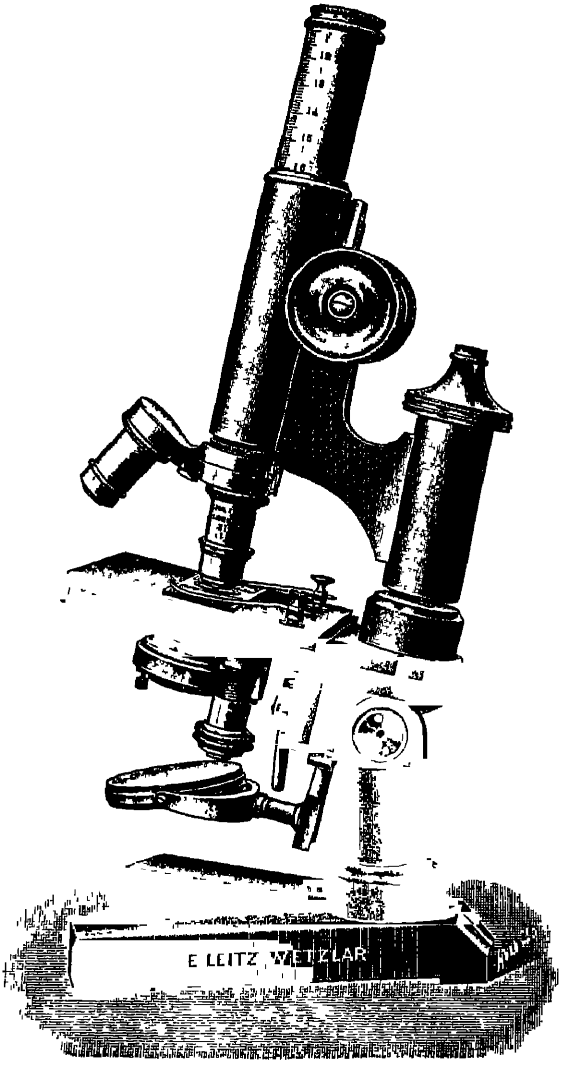

Fig 40 —Compound Microscope with Rack-and-Pinion Adjustment, Double Nosepiece, and two Objectives.

179. Notes on Use of Compound Microscope.—If the stand is without rack-and-pinion, see that the tube moves easily, but not too easily, up and down, if stiff, take out the tube, rub it with a little olive oil or vaseline and then with a dry cloth

See that the lenses are clean, dust the mirror, adjust it so as to send light through the body-tube, and insert first one eyepiece and then the other Rotate each eyepiece, if any specks are seen to rotate with it they must be on the eyepiece lenses, and should be removed with a chamois leather or soft cloth If the specks are dim, the dust must be on the objective; wipe the latter very carefully, and if necessary wash its front lens with a jet of water from a wash-bottle and wipe it dry Do not rub lenses much, or unnecessarily, put them away in their case when done with Do not unscrew the separate lenses of a high objective unless it becomes absolutely necessary, and then do it with great care; in cleaning the lenses do not remove the black coating on the inside of the tube

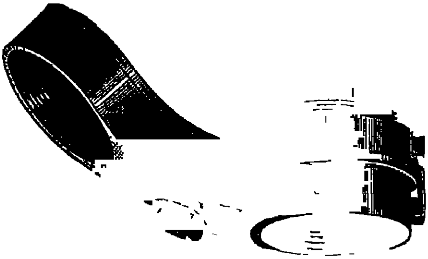

Fig 50 —Double Nosepiece.

Never use direct sunlight, and also avoid using artificial light. The best light is that reflected from white clouds in a northern sky. If a south aspect is the only one available, direct sunlight must be cut off, by using a white blind or fitting a piece of white card on the mirror

Always use the low power objective first, and never use the high power unless the object is covered with a cover-glass.

With the low power use a large hole of the diaphragm below the stage; with the high power use a correspondingly small diaphragm, otherwise (though the field may look brighter) the outlines of the cells, etc., will not be so sharply defined

Never use the fine adjustment until the focus has been obtained with the coarse adjustment, whether by sliding or by rack-and-pinion. With the low power objective (the one with the larger front lens), slide or rack down the tube to about $\frac{1}{2}$ inch from the object, then, looking through the eyepiece, slide or rack the tube upwards till the object comes into view, and focus clearly by turning the milled head of the fine adjustment screw to right or left. With the high power lower the tube to about $\frac{1}{4}$ inch from the object, then very carefully slide or rack the tube down while looking through the eyepiece, till the object just becomes visible, and focus with the fine adjustment

Great care is necessary in using the high power, since the objective when in focus is so close to the object Do not let the high objective touch the slide, and above all do not go on ramming or racking the tube down after passing the position of focus, or you may ruin the objective, besides breaking cover-glass and slide and damaging the specimen. Always use a cover-glass with the high objective; if you cannot see anything clearly, stop at once, move the tube upwards, wipe the objective, remount the specimen (if examined in a drop of water, which is liable to flow over the cover-glass and wet the objective), clean the cover-glass, and start again

Keep both eyes open when using the microscope, this lessens the fatigue of microscope work, and is not at all difficult if you practise for a few minutes each time you start work. Accustom yourself to using either eye indifferently. Never work by artificial light if you can help it

180. Accessories for Microscope Work.—The following apparatus is necessary for work with the microscope (Fig 51) :—

(1) A good razor, slightly hollow-ground or, better, with one side flat, and a strop and hone for sharpening it, cost of razor, about 1s 6d

(2) A few dozen glass slips, 3 ins × 1 in (4d per dozen)

(3) An ounce of $\frac{7}{8}$ in. square cover-glasses (No 2 thickness, 3s. per ounce).

(4) A pair of fine-pointed forceps (about 1s)

(5) A scalpel (about 1s) or a sharp pen-knife.

(6) A pair of fine scissors with sharp points (about 1s.).

(7) A few fine camel-hair brushes (about 1d. each)

(8) A few mounted needles (about 1s. 3d per dozen), these can be made by fixing a needle, point outwards, into one end of a penholder (Fig 51, D), or a handle adjustable for any needle (Fig 51, E) can be bought for about 9d.

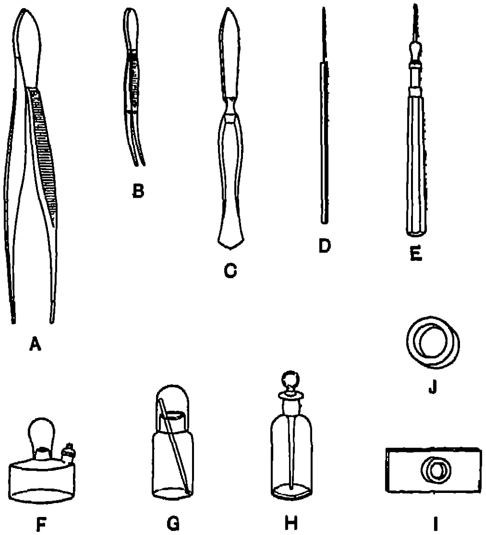

Fig. 51.—Accessories for Microscopic Work.

A, B, Forceps, C, Scalpel, D, Mounted Needle, E, Needle holder, into which fresh needles can be fixed, F, Spirit-lamp, G, Canada-balsam Bottle, H, Reagent-bottle with Dropping-rod, I, J, Glass Ring and Slide fitted with same, for cover-glass hanging-drop preparations.

(9) A few flat-bottomed watch-glasses (about 1s 6d per dozen).

(10) A few ointment-pots with lids, and a few wide-mouthed stoppered or corked glass bottles of different sizes

(11) A small spirit lamp (4 oz. size, 9d.).

(12) Gummed labels, $\frac{7}{8}$ in. square, for naming slides (2d. per hundred).

(13) A coarse duster, a finer cloth (*e.g.* an old, but clean, handkerchief), and a small chamois leather

(14) Bottle for Canada-balsam or glycerine-jelly, with cap and glass rod (2 oz. size, 8d). Fig. 51, G

(15) Small narrow-mouthed stoppered bottles for the following reagents; glass rods are used for bringing drops of the reagents from the bottles to the slide (Fig. 51, H).

(16) Reagents :—(*a*) **glycerine** diluted with an equal volume of water; (*b*) a 2% solution of **caustic potash** in water, (*c*) **iodine** tincture diluted with three times its volume of water; (*d*) **aniline chloride** solution; (*e*) a 5% solution of **common salt**; (*f*) **Schulze's solution** solution (chlor-zinc-iodine).

(17) Two **wash-bottles** (Fig 11), one for *alcohol* (methylated spirit, diluted with its own volume of water), the other for *water*

(18) Elder-pith for section-cutting (about 9d per bundle).

181. Cells in Apple Pulp.—Cut a "mealy" apple in halves, remove a small bit of pulp near the core, place it in a small drop of water on a clean slide, tease it out gently with two needles Carefully lower a clean and dry cover-glass over the drop, so that one edge is first wetted and no air-bubbles get in, hold the cover with dry forceps or support it with a needle and gently lower it. If air-bubbles get in, or any water flows over the upper side of the cover-glass, start all over again.

(*a*) Using the low power objective, note the numerous colourless *cells*, more or less egg-shaped, either isolated or connected in groups; some may have been injured by teasing, but most of them will be alive. Find a place where the cells are not too crowded, and put on the high objective Note, in a cell, the thin smooth *cell-wall*, lined inside by a film of fine-grained *protoplasm*, and the large cell-cavity (*vacuole*)

(*b*) Put a drop of salt solution on the slide, close to one edge of the cover-glass, but do not let it flow over the upper side of the cover (if it does, make a fresh preparation), then push a bit of blotting-paper along to the opposite edge of the cover, so as to *irrigate* the cells with the salt solution as the blotting-paper soaks up the water Watch the cells; the protoplasm film shrinks from the cell-wall as the cell is *plasmolysed*, but the wall itself shows no apparent change.

(*c*) Mount a fresh bit of pulp in the same way in a drop of water and irrigate with glycerine (or mount at once in glycerine), the cell is strongly plasmolysed, as with the salt solution, and the cell-wall also shrinks and becomes folded as the cell collapses

(*d*) Treat another preparation with iodine solution; the wall is not stained (or only stained faintly yellow or brown), but the protoplasm becomes dark-brown and a small rounded or oval body (*nucleus*) becomes prominent by staining more deeply than the rest of the protoplasm.

(*e*) Mount another preparation in Schulze's chlor-zinc-iodine, and let it stand for a few minutes; the protoplasm stains brown, as with iodine solution, but the cell-wall is stained violet (test for *cellulose*).

182. Spirogyra (Fig. 52).—Mount in water and examine with the microscope a small quantity of *Spirogyra*, a green filamentous freshwater Alga, commonly found in floating masses, in summer, on ponds and slow streams[1]

(*a*) The threads feel slimy, owing to a coating of mucilage on the surface. Notice the unbranched filaments, each consisting of a row of cylindrical cells, separated by cross-walls at intervals, and each containing one or more green spiral bands

(*b*) With the high power notice (1) the smooth, colourless cell-wall, (2) the thin film of granular **protoplasm** immediately within the cell-wall, in which are embedded (3) the flat **green bands,** which have ragged edges, and show at intervals small rounded highly refractive bodies, the **pyrenoids;** (4) the large central cavity (*vacuole*) of the cell, containing colourless transparent **cell-sap;** and (5) the highly refractive spherical or lens-shaped **nucleus** in centre of cell

(*c*) Stain some filaments with iodine, and observe that the pyrenoids have become dark purple or almost black, owing to the presence of crowded small **starch-grains,** and that the nucleus is connected with the outer layer of protoplasm by fine threads, each usually ending at a pyrenoid.

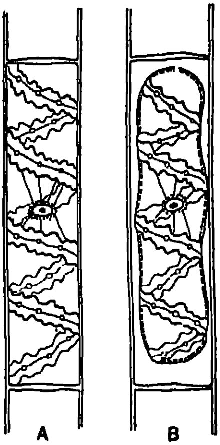

Fig. 52 —Spirogyra.

A single cell of a filament, showing normal (A) and plasmolysed (B) appearance of cell contents.

(*d*) Mount some *Spirogyra* filaments in water, place at one edge of the cover-glass a few drops of salt-solution, and while watching a filament, draw the solution under the cover-glass by holding a piece of blotting-paper at the other side Notice that the protoplasm shrinks from the cell-wall, as water passes by diffusion (osmosis) from the cell-sap in the vacuole into the salt-solution outside. Sketch the contracted or *plasmolysed* cell, then draw a little water under the cover in the same manner, and notice the cell return to its normal *turgid* condition.

(*e*) Place some *Spirogyra* filaments in alcohol, and after a day or two notice that the spiral bands have become colourless, the green colouring matter (chlorophyll) having been dissolved by the alcohol, which also contracts or plasmolyses the cells.

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[1] *Spirogyra* is supplied by Mr Bolton, 25, Balsall Heath Road, Birmingham, at almost any time, in shilling tubes. Any other material for practical work can be bought from Mr. Bolton, or from the British Botanical Association, Holgate Nurseries, York.

183. Other Simple Preparations.—Many other interesting and instructive preparations can be made by using fresh materials simply mounted in water, *e g* leaves of Mosses, of water-plants (*Elodea*, *Nitella*, etc.), roots of seedlings (note the root-cap, root-hairs, rootlets)

(*a*) Mount in water a few whole leaves of a thin-leaved Moss (try several kinds and select those which show large and clear cells), or a Fern prothallus Note the polygonal cells, joined to form a plate, without any spaces between them, and in each cell note the protoplasm, the vacuole, the nucleus (seen especially well on staining with iodine solution, which, however, kills the cell), and the numerous small disc-like chloroplasts or chlorophyll corpuscles (stained purple with iodine if they contain starch)

(*b*) In Moss cells you can see the chloroplasts in the act of dividing The chloroplast becomes lengthened and then nipped across the middle so as to resemble a dumb-bell, eventually separating and forming two chloroplasts.

(*c*) Get some Canadian Waterweed (*Elodea*), which grows abundantly in many rivers and canals, having long submerged stems and leaves arranged in threes at each "node" Mount a few leaves in water, and look for the *streaming movements* of the protoplasm, which may be started or hastened by gently warming the slide Similar movements can be seen, even better, in the long cells of Stoneworts (*Nitella* and *Chara*), which grow in sluggish streams, and the cells forming the hairs on the stamens of *Tradescantia* (often grown in greenhouses) show more complicated protoplasmic movements

(*d*) A "moist-chamber slide" is very useful for observing circulation of protoplasm in *Elodea*, etc., also for watching the growth of pollen-tubes A ring of glass is cemented to a slide, and the *Elodea*-leaf, or some pollen, is placed in a small drop on a cover-glass, which is then inverted over the ring A slide of this kind can be bought (Fig 51, I) or can easily be made by using a ring of cardboard

184. Section Cutting.—In examining the cellular structure of a solid mass, *e.g* a stem, root, or leaf, we can learn a certain amount by crushing, teasing, or macerating the tissues, but the best results are obtained by cutting thin *sections* in different directions Fresh tissues may be used for cutting, but it is often better to use "pickled" material The pickling fluid used for ordinary work is methylated spirit diluted with about half its volume of water Stems, roots, leaves, etc, preserved in this way in glass jars are always ready for use Delicate plants or parts of plants (flowers, etc) may be preserved in 4 to 6 per cent solution of formalin; formalin as sold is a 40 per cent. solution

In taking a section, the tissue to be cut should be held between the thumb and fingers of the left hand; the razor in the right hand The tips of the four right fingers should rest on the back of the razor, and the thumb in front, just behind the cutting edge The cutting edge is therefore directed inwards, towards the operator The arms should be brought up close to the body Tissue and razor should both be wet with alcohol The blade of the razor may rest gently on the forefinger of the left hand with the edge against the tissue Then the razor is drawn through the tissue with a sliding movement *With practice*, extremely thin sections may be cut

The sections should be removed from the razor by means of a brush, and placed in a watch-glass containing alcohol or water Several may then be transferred to a slide and examined in water under the low power, so that the best may be selected By means of the linen rag the excess of water may be removed, and iodine or other reagent added according to the special points which the student wishes to determine The reagent should then be washed off with water, the excess of water removed, a drop of glycerine added, and finally the cover-glass put on. The section should always be mounted in the centre of the slide The cover-glass should be rested on its edge and let down gradually by means of a needle The section *must not be allowed to get dry* during the process, or air-bubbles will make their appearance If these do appear, soaking the section for some time in alcohol will remove them. The cover-glass must be perfectly clean and dry

Neatness and cleanliness are of great importance in practical work At first you will find that the sections are rather thick and often obliquely cut These are difficulties which can be got over only by care and practice Do not attempt to draw a bad section

Very slender or delicate tissues, or thin structures like leaves, should be cut by embedding in pith or carrot If carrot be used, a piece 1 in × ½ in × ¼ in will be found convenient

185. Structure of Bean Cotyledon.[1]—A thin section across a Bean cotyledon shows an outer layer or skin (epidermis) of small cells containing only fine-grained protoplasm and a nucleus. The inner cells contain, besides protoplasm and nucleus, large starch-grains and small proteid-grains With iodine solution, the starch-grains are seen to turn blue, while the protoplasm and proteid-grains turn brown and the nucleus is deeply stained. The cotyledon has feebly-developed veins, appearing in section as irregular streaks and patches of small narrow cells.

The dry Broad Bean seed contains about 60 per cent of starch, 25 per cent proteids, 3 per cent. oil, and 4 per cent ash ingredients (calcium, magnesium, potassium, sulphur, phosphorus, etc); the residue consists chiefly of cellulose (in cell-walls) and some silica (in seed-coat)

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[1] See Slide No. 1 in *Plant Biology Collection of Micro Slides.*

186. Slide Mounting.—Sections and other specimens may be mounted *permanently* in **glycerine jelly** The bottle of jelly is set in a cup or dish of hot water until the jelly melts, then the superfluous water is drawn from the specimen by using a bit of blotting-paper, the specimen covered with a drop of melted jelly (taken out with a glass rod), and a cover-glass put over it. The jelly is apt to liquefy by absorbing moisture from the air, but this may be prevented by painting round the edge of the cover-glass with **a cement,** *e g.* Canada-balsam or gold-size

More lasting preparations are made by mounting in Canada-balsam, but all water must be extracted first, by washing or steeping in absolute alcohol, or in strong methylated spirit; then the specimen is treated with oil of cloves and (after removing excess of oil with blotting-paper) mounted in a drop of balsam

Preparations of *Spirogyra*, Moss leaves, or other green parts will often keep their green colour for a long time if the fresh specimens are mounted in a drop of acetate of potash (strong solution) and ringed with balsam or size.

187. Staining.—Many staining substances are used in advanced work, or to pick out the different tissues in sections of stems, roots, etc For instance, lignified (woody) cell-walls stain deep red with safranin, which does not stain cellulose walls or only faintly, haematoxylin stains cellulose but not lignified walls Instead of safranin we may use any aniline stain (*e g* aniline blue or violet) for lignified walls, and carmine instead of haematoxylin

In any case, the stain, dissolved in water or alcohol, is applied in drops to the specimen on the slide, or the specimen is dipped into the staining solution in a watch-glass and lifted out after some minutes with a brush, the stained specimen is then washed with water or alcohol, and if necessary placed in a second staining solution for double staining, *e g.* safranin and haematoxylin, or aniline blue and carmine, and finally mounted Ready-stained preparations (sections of stems, roots, leaves, etc) can be bought. The *Plant Biology Collection of Microscopic Slides* (see Preface) contains a good selection of preparations

QUESTIONS ON CHAPTER IV

1 Describe the parts of a compound microscope, with a sketch showing the parts labelled What is the use of a nosepiece, a cover-glass, a concave mirror, a draw-tube?

2. Describe the structure of a young parenchymatous cell and explain how it differs from that of a fully-grown cell of the same kind.

3. How would you obtain a living green cell for examination with the microscope? Describe, with sketch, the appearance of the cell, mounted in water.

4 How would you obtain, for microscopic examination, a living but not green cell? Sketch the cell as seen (*a*) in water, (*b*) in salt solution, (*c*) after treatment with iodine solution

5 Describe and sketch the cells seen in sections of (*a*) Bean cotyledon, (*b*) Date stone.

6 Describe the circulation of protoplasm as seen in any living cells you have examined, name the plant used and sketch one of the cells

7 Describe and sketch the appearance of a cell of Spirogyra, (*a*) in water, (*b*) in salt solution, (*c*) after treatment with iodine solution, (*d*) after treatment with alcohol

8 Describe, with sketches, what you have seen (i) with naked eye and lens, (ii) with the microscope, of (*a*) the structure of a grain of Wheat or Maize, (*b*) the origin of a rootlet, (*c*) the structure of a young stem, *e.g.* Sunflower.

9 Make a drawing of some living green cell which you have yourself observed Name the various parts you figure, and state in a few words the use of each in the life of the cell How was the cell obtained and prepared? By how many diameters does your drawing magnify the size of the original?

10 Explain the operation of cutting and mounting sections of plant structures for examination under the microscope Why are such sections cut thin?

11 How would you withdraw the water from a living cell without killing the protoplasm? Draw its appearance when thus treated, under the same power, and explain, so far as possible, the process that has taken place

CHAPTER V.

PHOTOSYNTHESIS.

188. Questions arising from Work on Seedlings.—The observations you have made on the growth of seedlings must have raised many questions, such as the following Why does the young main root grow vertically downwards, no matter how the seed is placed? Why does the shoot grow upwards? Why does a seedling remain yellow when kept in darkness and ultimately die, while a seedling set in the light has green leaves and keeps on growing? Is it possible to make a main root turn from the vertical direction which it usually takes? How does growth take place? Where, and how, is the force shown by growing roots and shoots developed? How would the growth of a young Bean-plant be affected if one cut off the cotyledons, or the root, or the shoot? How does the seedling get food when that stored in the seed is all used up?

The only way in which one can gain any real knowledge on these points is to put each question to a living plant and make the plant itself give the answer—in other words, to make experiments. Write down any other questions that occur to you as your work proceeds. In each case keep a record of (1) the inquiry, (2) methods and apparatus used, (3) observations and results, (4) inferences.

189. What are the Chief Functions of the Root?—Refer to the parts of Chapter I. in which the root of the Broad Bean is dealt with, go over the observations you have made on the roots of seedlings which you have grown, and examine the roots of as many plants as possible, wild and cultivated, pulling or digging them up and examining them as directed in Chapter I. for the root of Broad Bean. What characters do nearly all roots appear to possess in common, from your own observations on roots of various plants? What do you think are the chief uses, or functions, of roots? How could you test your ideas on this subject by simple experiments? Try any methods that occur to you, before going further See Chapters X. and XI.

* (*a*) In a Bean seedling grown in sawdust or soil, cut across the main root just below the cotyledons: the plant falls over Support the plant by tying it to a stick, and keep the soil or sawdust moist around the cut place; notice the new roots formed from the lower part of the stem.

* (*b*) Repeat (*a*) with another seedling, planted by itself in a pot or box, but after tying it to a stick allow it to remain *unwatered* What changes does it show, from day to day, in the colour, shape, and position of the leaves, and in any other respects? How would you describe these changes, and what ultimately becomes of the shoot? For comparison, allow some *uninjured* seedlings to remain unwatered do they show the same changes? What do these simple observations prove as to the work of the root?

* (*c*) Fix a seedling with its root dipping into water in which some powdered vermilion has been shaken up vigorously After an hour or two, cut across the root a short distance above the surface of the coloured liquid Has any of the colouring-matter (which consists of grains *suspended in the water*) entered the root?

* (*d*) Fix a seedling with its root dipping into red ink (colouring-matter *in solution*), and after a time (try several seedlings, and give them different lengths of time) cut across the root, to see how far upwards the colour has spread, and in what part of the root it travels Also cut across the *stems* of seedlings that have been in red ink for a day or two, and notice the red-stained bundles how does the liquid travel in the *leaves*?

The root, therefore, fixes the plant in the soil and also absorbs water and passes it upwards through the stem into the leaves The water absorbed from the soil is not *pure* water it contains dissolved substances of great importance in the nutrition of the plant, as we shall see later

Do you know of any plants whose roots have other functions besides those of fixing the plant and absorbing water with dissolved salts?

190. What are the Chief Functions of the Shoot?—It is very easy to see that the *stem* of a plant like the Broad Bean has at least two duties to perform—(1) to carry the leaves and keep them spread out to the air and the light,

(2) to carry up to the leaves the water absorbed by the root Stems have other kinds of work to do besides these, as you will see as your observations and experiments continue

191. How do Plants Feed?—After the seedling has used up the food laid up for it in the seed (in the embryo itself or in another part of the seed), it must, in order to go on living and growing, get food in some other way. From what sources, and by what processes, does the plant obtain food? What substances does the plant need for healthy life and growth?

192. Effect of removing the Cotyledons.—Seedlings grown in darkness lose in dry weight and eventually die (Art 141), the smaller the amount of food stored in the seed, the shorter is the life of the darkened seedling Some further experiments will serve to emphasise this point.

* Remove (*a*) one cotyledon, (*b*) both *cotyledons*, from soaked Broad Beans just beginning to germinate Place some of these seeds, along with untouched seeds, in the light; place others, also with untouched seeds for comparison, in darkness.

* **193. Effects of removing Foliage-Leaves.**—Remove the *foliage-leaves* from (1) a young Bean-plant which has not yet used up the food in its cotyledons, (2) an older plant whose cotyledons have fallen off (if they have shrunk considerably, but are still attached, pull them off) Does the removal of the foliage-leaves check the growth of the plant, as compared with that of similar plants left untouched? In which case, (1) or (2), is the effect greatest?

194. Comparison of Cotyledons and Foliage-Leaves.—We have seen that the cotyledons of the Broad Bean resemble the foliage-leaves in the fact that branches arise in their axils By growing a seedling in coloured water it can be shown that the cotyledons have veins, which can also be seen in sections examined with the microscope. It is always a useful plan to tabulate—*i e.* to write down in parallel columns—the chief differences between different plants or different parts of the same plant, as regards their position, form, structure, etc —and then to find out as completely as possible, by observation and experiment, the *reasons* for these differences In comparisons of this kind always try to discover whether differences in *structure* can be explained as due to differences in *function*

Cotyledons.	**Foliage-Leaves.**
opposite	alternate
small	large
simple	compound
pale yellow	green
thick	thin
veins obscure	veins conspicuous
no stipules	stipules present
remain below ground	formed above ground
gradually turn smaller	gradually turn larger
fall off after a time	remain on a long time

Can you add any further differences? Try, as you proceed with your study of the green leaf and its work, to explain these differences in form, texture, duration, etc, between the cotyledons and the foliage-leaves of the Broad Bean

Gather and examine leaves of various kinds, living or fallen, evergreen or deciduous, stalked or unstalked, simple or divided (compound) What is there common to nearly all leaves, however they may differ in detail? In what surroundings do you find plants with thick fleshy leaves? Does the general broad and thin form of the leaf-blade suggest anything as to the functions of the leaf? Do most leaves seem to expose as much surface as possible to light and air? We saw that the seed-leaves of Broad Bean and of many other plants contain food, and that if they are removed from a soaked seed which is beginning to germinate, the growth of the young plant is stopped.

195. Do Leaves contain Food?—We have seen that seed-leaves often contain food-materials—*e g* starch, proteids, oils It will be easy to find out whether foliage-leaves contain any of these foods. Let us test them for the presence of starch, by using iodine solution. To do this we must try to remove the green colour

* Boil in water some leaves taken from a Bean seedling, or some other plant with thin flat leaves, which has been growing in the light The colour does not come out. Place the boiled leaves in alcohol, and notice

that the leaves gradually lose their colour, while the alcohol turns green Try several different plants: in some the extraction of the green substance takes place very slowly, in others (e.g Broad Bean, Tropaeolum or "Nasturtium," Primrose) much more quickly [1] When the leaf is colourless, place it in a saucer and pour dilute iodine solution over it The depth of colour produced shows roughly how much starch is present. If there is abundance of starch, the colour is nearly black; if little starch, it is bluish, if no starch is present, the iodine turns the leaf brownish (the test for proteids)

196. Does the Green Leaf make Starch?—Where does the starch come from? Is it *made* in the leaf? Does it come from the soil? If a plant were set in darkness for some days, would its leaves still contain starch?

* Keep a plant in darkness until the leaves no longer show starch when tested with iodine, then cut off several leaves and set them in tumblers or bottles of water; the stalk should dip into the water. Set some in sunlight, the others in darkness, and after two days decolorise and test with iodine the two lots of leaves Those kept in darkness show no starch, but starch is found in those that have been exposed to light This means that starch is *made* by leaves when in the light, but not when in darkness.

197. Is Light required for Starch-Making?—The preceding experiments show that starch is found in leaves that have been exposed to light, whilst it is absent from the leaves of the same plant after it has been kept in darkness for a day or two This suggests (1) that light is required for starch to appear in the leaf, (2) that the starch formed in the light disappears in darkness.

* Set some plants—e g Broad Bean, Primrose, Tropaeolum—in pots in darkness for at least a whole day. In the morning take off some of the leaves, decolorise them, test with iodine, they give only a light brown colour, starch being absent Choose a day with sunshine or good diffused light for these experiments.—

(*a*) Let some of the leaves on the plant remain untouched

(*b*) Fix a strip of tinfoil across the leaf, on both sides (above and below); or pin to the leaf two flat slices of cork opposite each other on the two sides, or stitch to the upper side of the leaf a piece of black paper or cloth. The object in each case is, of course, to exclude light from a portion of the leaf.

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[1] Do not *boil* leaves in alcohol; this is dangerous, wasteful, and (if suitable plants are used) unnecessary.

(*c*) With a knife or scissors, cut the words "starch," "light," your initials, etc., in capital letters out of a series of cards, fasten each card to a broad leaf (a Primrose plant, dug up and grown in a pot, or in a jar of water, answers well), and, after letting the plant stand for a full day in darkness, expose it to light for several hours, then decolorise and test

In each case expose the plant to light from morning till late afternoon, then take off the leaves which have been treated in these various ways, tying to each a label, decolorise them and test with iodine solution. Make notes of your observations and conclusions as to the conditions under which starch is made by leaves. After being tested with iodine, the leaves may be preserved in alcohol and thus made colourless again, and on being soaked in hot water will again give the starch reaction with iodine **The same leaves can therefore be used again and again**, starch once formed remains in leaves which have been killed by boiling In teaching, however, it is always better to start experiments from the beginning.

198. Is Air needed for Starch-Making?—We have already used a simple device for finding out whether any part of a plant contains air and bears openings (Arts 18, 35)

* (*a*) Dip the leaves of various plants into very hot (just boiled) water in a warmed tumbler, and notice the expulsion of air-bubbles In many leaves the bubbles only appear on the lower surface, *e g* Laurel, Rhododendron, in others they appear on both sides, but more abundantly on the lower surface, *e g* Broad Bean Cut a large leaf (*e g* Laurel) across and dip the cut edge under water, observing the streams of bubbles given off

* (*b*) Try to blow through leaves dipping into water, first with the stalk and then the blade under water The simple apparatus shown in Fig. 53 may be used to suck air through a leaf. Suitable leaves are Lesser Celandine, Chinese Primrose, Marsh Marigold, Water Lily

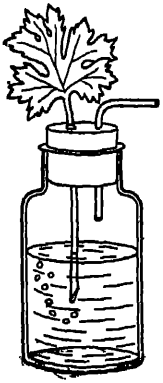

Fig 53.

* (*c*) Even when one cannot force air through a leaf with the lungs, the presence of air-spaces and of openings on the surface can easily be shown by using an air-pump or exhausting syringe to suck air through, or a bicycle-pump to blow air through. The leaf-stalk should be fixed in a bored cork, with another hole for a short glass tube to connect with the syringe or pump by means of rubber-tubing. The cork is fixed into a wide-necked flask or bottle, and the whole made air-tight by means of plasticine and vaseline.

The openings by which the air inside the leaf communicates with the outside air (atmosphere) are called *stomates*, a term meaning "mouths."

* *(d)* Smear the *lower surface* of a leaf with vaseline; this will block the stomates, which in many leaves are mostly or even entirely found on the lower surface. Find out the distribution of stomates on the two sides of each leaf you experiment with by tearing off and examining with the microscope pieces of the lower and the upper skin. If you have no microscope, dipping the leaf into hot water gives a rough idea on this point.

* (*e*) Smear a small circular area of the leaf with vaseline, applying it to *both sides*, so that this part of the leaf will be shut off on both sides from communication with the atmosphere through the stomates.

* (*f*) Smear with vaseline the *upper* surface of another leaf.

* (*g*) Smear *both* surfaces of another leaf.

The results of these simple experiments will show that the air is concerned with the process of starch-making. What about leaves which grow in water, like those of submerged aquatic plants?

* (*h*) In an experiment on germination we prevented the access of air to seeds by covering them with water, and in the preceding experiments we have excluded air by covering the leaf with vaseline. Tie the stalks of the leaves of some ordinary land-plants to a stone and sink them under water in a glass jar. Expose to light, and afterwards test the leaves for starch.

* (*i*) Repeat the last experiment with the leaves of a plant which lives submerged in water—*e.g.* Water Starwort, Canadian Water-weed, or any other plant you find growing below water in ponds or streams. Do these submerged leaves possess stomates?

199. Structure of the Leaf.—A fuller knowledge of the structure of the leaf will help us to understand its functions better. Even if you have no microscope, you can learn a good deal about leaf-structure by simple methods.

The leaf (Fig. 54) is covered externally by a layer of flattened cells (skin or *epidermis*), and the outer walls of these skin-cells are chemically changed, the cellulose being *cutinised* by the addition of a substance (cutin) which is almost impermeable to water and gases. This substance, which resembles cork in some respects, is most abundant in the outer part of the cell-wall, so that the epidermis is covered by an outer sheet or **cuticle**. The cuticle acts as a protection against drying; it is especially well developed in plants that grow in exposed situations and in "evergreen" plants, while it remains undeveloped in plants which grow submerged in water.

The epidermis is discontinuous at certain points, leaving narrow oval apertures called **stomates**, each of which is surrounded by a pair of special curved guard-cells The latter are able to open or to close the stomates, for when they are quite tense (*turgid*) they curve apart, but when less so they collapse and come together The stomates are very minute but extremely numerous, and in *bifacial* leaves which have distinct upper and lower surfaces, they are usually more abundant on the lower surface.[1]

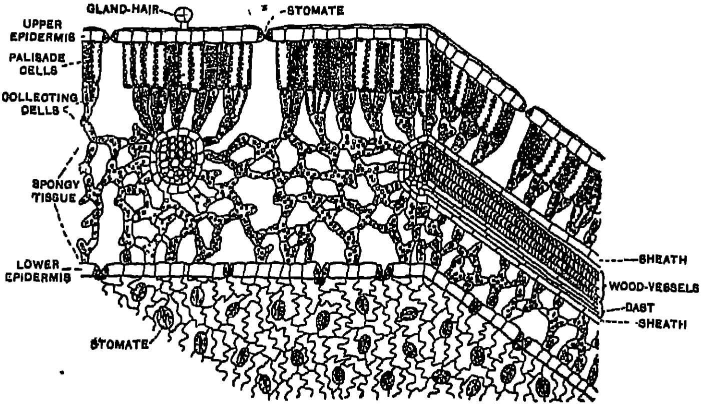

Fig 51 —Structure of Part of a Broad Bean Leaflet.

The centre of the leaf is occupied by ground tissue, through which strands of conducting tissue run, the latter being the "veins" of the leaf. In bifacial leaves the ground tissue (*mesophyll*, or central-leaf tissue) is usually divided into an upper region in which its cells are long and narrow in the vertical direction (*i e.* lengthened at right angles to the surface of the leaf), and a lower region in which the cells are branched and loosely arranged. The upper tissue (palisade tissue) is compact, the cells being close together or separated only by narrow spaces, whilst the lower tissue (spongy tissue) contains large spaces between the cells The cells of the palisade and spongy tissue all contain green grains, so do the guard-cells of the stomates, but not the other cells of the epidermis, nor those making up the veins

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[1] A square millimetre of Broad Bean leaflet gave, as the average of several countings, 90 stomates in the upper epidermis, and 140 in the lower; a leaflet with area 10 sq cms. therefore bears over 200,000 stomates.

It is easy to discover that the spaces between the cells of the middle tissue of the leaf contain air, and that they communicate with each other throughout the leaf, with the air-spaces in the corresponding tissue (ground tissue, cortex) of stem and root, and with the external air by means of the stomates The green grains (chloroplasts) present in the middle tissue (mesophyll) and in the guard-cells contain chlorophyll, which can be dissolved out of the grains, leaving them colourless.

* (*a*) The following is a good method of examining the structure of a leaf Boil some small entire leaves (those of Box or Privet answer well) in caustic potash for about ten minutes Hold a leaf under water, and with scissors cut off a strip round the margin, the leaf is then readily separated, with the aid of a mounted needle, into three parts, which should be mounted on separate slides and examined with the lens, and then covered with a cover-glass and examined with the microscope The three parts are (1) the upper skin or epidermis, (2) the middle tissue or mesophyll, containing the veins, (3) the lower skin.[1]

The upper and lower skins are thin and transparent, each one cell in thickness, they are, of course, continuous with each other at the edge of the leaf In the upper skin all the cells fit closely together without any spaces between them, but in the lower skin there are numerous openings (stomates). Tease the middle tissue with needles, so as to separate the cells in one portion; notice the shapes of these cells, some being cylindrical, others branched. You will probably find some of the cylindrical cells still attached to the inside of the upper skin, and some of the branched cells to that of the lower skin.

* (*b*) Fold a large leaf (*e g.* Laurel or Rhododendron) several times, and cut thin sections, keeping the razor wet with alcohol. Mount in water, examine with a microscope, and sketch a thin part. Cut some

sections with the razor dry, and mount in water, notice the presence of numerous irregular air-bubbles between the cells of the spongy tissue, then run in some alcohol and observe the expulsion of most of the air in the form of spherical bubbles This shows that the spaces between the cells of the spongy tissue contain air. How did this air get in? Examine thin sections and try to find stomates leading into the air-spaces

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[1] See preparations of Box-leaf, made in this way, in the *Plant Biology Collection of Microscopic Slides.*

* (c) Strip off a piece of the lower epidermis (Broad Bean, Narcissus, Arum, and Ivy-leaved Toadflax answer well), mount in water, and examine with the microscope Notice the stomates (are they open or closed?) and the presence of chlorophyll-grains in the guard-cells (do they occur in the other cells of the epidermis?). Find an open stomate with the high power, put a drop of 3 per cent salt solution at one side of the cover-glass, and draw it through with blotting-paper Notice the effect of this on the stomate Now put a drop of water at one side and draw it through, until the stomate opens again. Sketch the stomate opened and closed The salt solution draws water out of the guard-cells, and then the stomate closes as the guard-cells lose their turgidity and collapse When water is added, the guard-cells absorb it and swell up, becoming turgid, and the stomate opens

* (d) Cut sections of leaves that have been exposed to light for several hours. Examine some sections to see what parts contain the green grains, then treat others with alcohol and test with iodine. Notice that starch-grains occur only in cells which contain chlorophyll. Tear off bits of the upper and lower epidermis-layers, and notice that only the guard-cells of the stomates contain starch The starch-grains are very small and are formed inside the chlorophyll-grains.

200. Is Warmth needed for Starch-Making?—It is very easy to find out whether temperature has any influence on starch-production by leaves Place a leaf in a saucer or jar kept cold by ice, expose to light, and after several hours test for starch.

201. Is Chlorophyll needed for Starch-Making?—Have you noticed, in your experiments with leaves of Broad Bean, Tropaeolum, or Primrose, that the *veins* remain unstained even when the rest of the leaf is black with the iodine-test? This in itself shows that starch is only formed in the **green** parts of the leaf.

* (a) Try variegated leaves (e g varieties of Geranium or Ivy), making a careful drawing of each leaf before it is decolorised and tested with iodine, and observe that only the green parts produce starch. In leaves whose veins are colourless, or nearly so (e g Primrose), owing to the absence of chlorophyll above and below them, you will notice that the veins stand out from the rest of the leaf when the iodine-test is applied, by the absence of starch.

* (*b*) Grow seedlings (Bean, Pea, etc) in darkness, then put them in the light for a day and test the leaves for starch Leave them in the light until their leaves turn green, then test again for starch.

These results show that the green substance (chlorophyll) is essential for the process of starch-making by leaves

202. How is Air concerned in Starch-Making?—We know from previous experiments that starch can be broken up, by heating it, into carbon dioxide and water, and that carbon dioxide is always present in the air, being produced by all processes of burning when the substance undergoing oxidation contains carbon We shall see later on that a plant increases in dry weight when grown in a culture solution which contains no carbon, though more than half of the plant's dry weight consists of carbon

If you consider these facts carefully you will probably conclude that the carbon in the starch made by the leaf comes from the carbon dioxide in the air. Does the leaf in some way make carbon dioxide and water come together to form starch? If so, a plant which is exposed to light and is making starch must be taking carbon dioxide from the air Again, if the carbon dioxide of the air is the source of the carbon used in starch-making, what will be the effect of exposing green leaves, in light, to air containing no carbon dioxide?

* (*a*) Heat in a dry test-tube (1) pieces of laundry-starch, (2) leaves, (3) pieces of stems, (4) pieces of roots, (5) any other plant tissues Notice that water is given off as vapour which condenses in the upper part of the tube, and that a black charred mass remains (charcoal, i e. carbon) Fix a J-shaped tube into a cork to fit the test tube, and let the longer limb dip into lime-water in a bottle or test-tube, notice that carbon dioxide is given off, causing a white precipitate, when these substances are strongly heated These experiments show that all parts of plants contain carbon, and that starch (the formation of which in plants has been proved in the preceding experiments) also contains carbon.

* (*b*) Put a "Nasturtium" (Tropaeolum) leaf in a small bottle containing water, so that its stalk dips well into the water while its blade rests on the neck of the bottle Pour some caustic potash into a wide-necked glass jar, and lower the bottle with the leaf into this jar, then cork the jar tightly, and smear the edges of the cork with vaseline The leaf should be taken from a plant which has previously been kept in darkness for two days The leaf is now exposed to air whose carbon dioxide is absorbed by the potash solution. Set up a control experiment in which the arrangements are the same, but leave the jar open

or cover it with a cork (or a piece of wood) in which a hole is bored to admit air

* (*c*) Use the same apparatus, but, instead of pouring caustic potash into the jar, pass through a hole in the cork closing the jar the tube of a funnel which is filled with soda-lime, or with lumps of caustic potash This will admit air, but absorb the carbon dioxide it contains As a control, use a similar apparatus, but place in the funnel gravel instead of soda-lime or potash

* (*d*) Fit a wide-mouthed bottle with a cork cut in two across the middle Smear with vaseline the edges of each half of the cork, pour some clear lime-water into the bottle Then lay the bottle on its side and place between the halves of the cork a primrose leaf of convenient size, so that half the leaf is inside the bottle and the other half outside (Fig 55) The base of the leaf, outside of the bottle, should dip into water in a small dish See that the halves of the cork are securely sealed with vaseline, then cover the whole apparatus with a large bell-jar, and set it in a good light After some hours, remove the leaf, decolorise, and test with iodine If the experiment has been properly arranged, the part of the leaf inside the bottle (*i e.* in air free from carbon dioxide, which has been absorbed by the lime-water) contains no starch, while the part outside it does. If you do not get this result at first, try the experiment again This is known as Moll's experiment. Baryta-water or potash may be used.

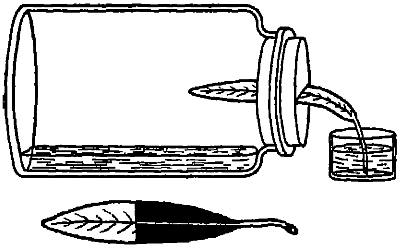

Fig 55 —Moll's Experiment.

203. How is the Volume of the Air affected by Starch-Making ?—If some living leaves are placed in a closed vessel, how does their absorption of carbon dioxide affect the volume of the air ? Does the volume diminish ?

* Place a few fresh leaves (from a plant which has been previously kept in darkness for a day) in a glass jar fitted with a bored cork

through which passes a twice-bent tube (J-tube) and let the outer limb dip into water coloured with red ink in a small bottle, as in Fig. 36. Charge the air in the jar with carbon dioxide as before, cork tightly and seal with plasticine or vaseline Cause the coloured water to rise a little way in the outer tube, by warming the jar gently and then letting it cool Mark the level when the preparations are complete, and set the apparatus in good light (not direct sunlight)

Does the volume of air in the apparatus (and therefore the level of the water) alter at all? Since changes in temperature affect the level (why?), it is well to prevent draughts by placing a bell-jar over the apparatus, or to set up a control experiment (omitting only the leaves); note the temperatures by hanging a thermometer near the apparatus or passing it through a hole in the cork of the jar Test the air in the jar for carbon dioxide after a day's exposure to light, by pouring in some lime-water or baryta-water This experiment shows that **when carbon dioxide is absorbed by green leaves, an equal (or nearly equal) volume of some other gas is set free**

204. How does Starch-Making change the Composition of the Air?—Have you ever noticed, on a warm sunny day, brisk streams of gas-bubbles arising from plants growing under water in a pond or an aquarium?

* (*a*) Collect some of these submerged water-plants—*e g* Water Starwort (*Callitriche*) or Canadian Water-weed (*Elodea*)—and test their leaves for starch Place them in a large glass vessel (*e g* a bell-jar resting on a wooden support), if necessary tie them to a stone to keep them together at the bottom Are the gas-bubbles given off in darkness? Cover the vessel with a black cloth and see if the bubbling stops after a short time, then expose the vessel to light again. Water-cress or Mint will do, if the plants mentioned cannot be obtained

* (*b*) What do these bubbles consist of? Is the gas ordinary air, or oxygen, or carbon dioxide? We know that water contains dissolved air, and that this dissolved air is richer in carbon dioxide than ordinary air Press a glass funnel down on the plants, and either fit a piece of rubber tubing to the tube of the funnel, or, better, invert over the latter a test-tube filled with water, so as to collect the gas given off by the plants That this gas is **oxygen** (in reality, *air rich in oxygen*) can easily be proved by its causing a glowing splinter of wood to burst into flame, or by corking the end of the tube while still in the water, transferring the tube to a vessel containing solution of pyrogallol in caustic potash and opening it, when the gas will be almost entirely absorbed by the solution (see Art. 76).

* (*c*) Keep your water-plants in darkness until the leaves show little or no starch, then transfer them to water which has been boiled (to expel the dissolved gases) and then cooled. Expose them to light, with funnel and test-tube as before Is any oxygen given off by the plants, and do they make any starch?

205. Which Parts of the Plant absorb Carbon Dioxide?—Are the leaves (or other green organs) alone able to absorb and use the carbon dioxide of the atmosphere?

* (*a*) Get five wide-mouthed bottles, with tightly fitting corks Wash each bottle out with water, to keep the air inside it moist, and label each with a number (1 to 5) Leave 1 empty, to serve as a check or "control." Into 2 and 3 put some living green leaves; into 4, some green leaves which have been killed by boiling, into 5, some pieces of living wood cut from a branch, or some roots, or mushrooms, or any other living but *not green* tissue Charge the bottles with carbon dioxide by breathing into each several times Another plan is to pour into each jar some "plain soda-water" from a syphon (a convenient method is to use a Sparklet syphon, charging it without adding soda), the "soda-water" is of course simply water charged with carbon dioxide. Cork each bottle tightly, smearing the edges of the corks with vaseline Place bottle 2 in the dark, the others in the light, for a whole day Then test each bottle for carbon dioxide by pouring in a little lime-water and seeing whether it turns milky.

Try the experiments several times, and record your results, with the inferences to be drawn from them If carefully carried out, these experiments will show (1) that living green leaves absorb carbon dioxide from the air in sunlight, (2) that they do not absorb it in darkness, (3) that dead leaves do not absorb carbon dioxide, (4) that living but not green parts of plants do not absorb it.

* (*b*) Repeat the observations on the giving-off of oxygen by water-plants, but put into the water, along with the water-plant, pieces of living roots and of mushrooms Do these living but not green tissues give off oxygen? If any gas-bubbles escape from them, do they come off in light only, or in darkness as well?

206. Does the Leaf gain in Weight by making Starch?—We saw that seedlings grown in darkness lose in dry-weight, while seedlings exposed to light gain in dry-weight It is easy to prove that the loss and the gain are due chiefly to loss and gain of *carbon. How* could you prove this by experiment? To what process do you suppose the gain in dry-weight is due when a seedling is grown in the light? It is very easy to find out.

(*a*) Take a plant which has been growing in the light, and set it in darkness for a day or two—until a leaf picked off, decolorised, and tested with iodine, shows no starch Remove a second leaf, kill it by holding it in the steam issuing from a boiling kettle, dry it in an oven, or simply put it in a warm dry place, and weigh it Now expose the plant to bright light for several hours (from morning until evening), remove a third leaf (as nearly as possible similar in size to the second), dry and weigh it, and compare its dry-weight with that of the second leaf If a Broad Bean seedling or a Tropaeolum plant be used, it will be easy to select leaflets, or leaves, of the same size.

(b) Repeat the preceding experiment, using leaves severed from the plant and set in water in small bottles or tubes

(c) A more accurate result will be obtained if you use *pieces of the same leaf* for comparison Use a plant with large leaves, e g Sunflower, Primrose, Vegetable Marrow, Rhubarb If the plant used is growing in a pot or box, keep it in darkness overnight, if it is growing out-of-doors, you must either get up with the sun to start the experiment or, if practicable, cover the plant in some way the previous evening so that it gets little or no light until you are ready to begin

Choose about six symmetrical leaves, divide each in two longitudinally, cutting along close to the midrib Find the area of the removed half-leaves by cutting out a paper model of each half-leaf and weighing the papers against strips of similar paper an inch (or 2 or 3 inches) wide, until by balancing you get the total area of the half-leaves Kill these with stem, dry them, and record the dry weight Expose the plant to light until evening, remove the remaining half-leaves (cutting along by the midrib), dry, and weigh.

Experiments of this kind have shown that the leaves of Sunflower and Vegetable Marrow produce in a summer day of fifteen hours about an ounce of starch per square yard of surface The increase in weight due to starch-formation does not represent the total amount of carbohydrate material produced, in the Sunflower, for example, only one-sixth of the manufactured carbohydrate appears as starch, the remainder being largely carried from the leaf to other parts of the plant as sugar

207. Carbon Assimilation ; Photosynthesis.—In the green leaf exposed to light and air a somewhat complicated series of processes goes on, leading usually (but with some exceptions) to the appearance of *starch* at one stage What we have learnt from our experiments on plants, together with our knowledge of the composition of water and of carbon dioxide, would seem to suggest that a process of *synthesis* occurs in the green parts of plants We have seen that one method of proving the composition of water is to produce it by synthesis—*i e.* by bringing together hydrogen and oxygen gases and making them unite to form water. Many complex substances, *e g* sugars, can be produced by synthesis

When starch is heated, carbon dioxide and water are given off This suggests that possibly carbon dioxide and water are brought together, in the green leaf in sunlight, to form starch. This is not exactly what happens, but the fact that a plant can, when supplied with water and carbon dioxide, make starch (containing carbon, hydrogen, and oxygen) suggests that water must be concerned in the process The formation of starch in a plant exposed to light is clearly seen in a simple water-plant like Spirogyra (Art. 182); this plant, placed in water containing a few simple salts (Art 230) and carbon dioxide, produces starch within a few minutes after exposure to light after having been kept in darkness

It is therefore obvious that in some way carbon dioxide and water are broken up and their elements rearranged in such a way as to produce carbohydrates, oxygen being given off in volume equal to that of the carbon dioxide absorbed

Is it possible, by any artificial method, to cause the atoms of carbon, hydrogen, and oxygen in carbon dioxide (CO_2) and water (H_2O) to arrange themselves so as to form an organic substance? To break up carbon dioxide into carbon monoxide (CO) and oxygen requires great heat How can water be broken up (analysed) into its elements? It is clear that a large amount of energy is required to effect these two processes of decomposition But carbonic acid (carbon dioxide dissolved in water) can be decomposed by a comparatively weak electric current ("silent discharge").

Here we come to an interesting point—the chief product of this electric action is formaldehyde (CH_2O), a substance which in watery solution ("formalin") is used for preserving and disinfecting Now, by various simple methods (*e g* boiling with lime), formaldehyde can be converted into a sugar, its molecules being condensed or packed together to form the large sugar-molecules ($C_6H_{12}O_6$)—this process is sometimes called polymerisation

In green plants, sugar—usually, however, cane-sugar ($C_{12}H_{22}O_{11}$)—is formed in the green leaf-cells, though starch is the first *visible* product; the starch appears as grains inside the chloroplasts, while the sugar is dissolved in the cell-sap Probably part of the sugar produced is converted into starch because the excess of sugar dissolved in the cell-sap would cause injury to the living substance (protoplasm); the starch, practically insoluble in water, is evidently a temporary storage substance, which is later removed after being converted back into sugar.

Formaldehyde is a poisonous substance, its solution ("formalin") being used as a germ-killer. Yet it occurs in small quantities in leaves, and a green plant like Spirogyra can make starch when placed in water containing no carbon dioxide but containing a substance which readily breaks up and yields formaldehyde.

It is now known that (1) the amount of formaldehyde produced in assimilating leaves varies in exactly the same way, according to the intensity of illumination, as (2) the amount of carbon dioxide used and (3) the amount of starch formed, being greatest in diffuse light, least in intense light or in darkness. Further, it appears that (4) the strength of the electric currents in green organs also varies according to the light-intensity. The optimum, in all four cases, is about one-fourth of direct sunlight.

It has therefore been concluded that the light received by the green tissue is transformed into electric energy and that this energy causes the production of formaldehyde from carbon dioxide and water.

The term **photosynthesis** is often applied to what we have so far called "starch-making," because it includes a building-up of simple inorganic substances into complex organic substances. The term **photolysis** has also been used, because the earlier stages involve a breaking-down of carbon dioxide and water. The simpler term **carbon-assimilation** is perhaps better than either.

The term **photosynthetic carbon-assimilation** is used to distinguish the normal process in green plants from the **chemosynthetic carbon-assimilation** carried on by certain Bacteria (nitro-bacteria) which use carbon dioxide but do not obtain energy from light. A green plant can grow and make starch when deprived of carbon dioxide, but supplied with sugar or with glycerine Light is not required for this form of assimilation.

208. Why is Light required for Photosynthesis?—Since energy is required for the carrying on of photosynthesis and is essential for this process, it is obvious that light is necessary because it is the source of energy. The energy used is stored up in potential form in the organic substances produced It is important to study some of the properties of light

209 Cause of Light —Light, like heat, is believed to have its origin in vibration of the molecules of the luminous body, and to be transmitted to the eye by means of undulations in an intervening medium. And, since light can pass freely through a perfect vacuum and through interstellar space, the medium required for its transmission cannot be of a molecular nature It is an imagined continuous substance which is called the *ether*. It is quite unlike any form of matter with which we are acquainted It is probably devoid of weight, and is perfectly elastic. The ether is supposed not only to occupy all space, but to interpenetrate all matter, and to lie between the molecules of even the densest solids, as air lies between the leaves and branches of a tree

It may now be possible for us to picture to ourselves the vibration of the molecules of the luminous body setting up wave-movements or undulations in the ether which travel with inconceivable speed (about 186,000 miles per second, a speed that would carry it 7½ times round the earth in a second) in all directions Some of these undulations, falling on the eye, there set up changes in the optic nerve which, when transmitted to the brain, produce the sensation of light

Light is invisible Remembering what light is—simply undulations in an invisible medium—this statement ought to cause little surprise. When we apparently see a beam of sunlight entering through a small window into an otherwise dark room, what we really see is not the light itself, but a number of floating dust particles in the air illuminated by the beam Many of these are so large as to be easily visible separately as dancing motes If a lighted Bunsen burner be brought below the beam so as to burn up or volatilise these particles, the luminous track will be interrupted by what appears to be black smoke rising from the flame But the Bunsen flame is perfectly smokeless, and the black spaces are full of dust-free air, consequently there is nothing in those parts to reflect the light, and it remains invisible.

210. Intensity of Light —Light, like radiant heat, is a form of energy, and therefore capable of measurement The quantity of light in any space at any instant is measured by the corresponding amount of energy in that space at the instant considered, and the intensity of the light is measured by the energy transmitted through that space in unit time. This measurement cannot be made directly; but, for light of a given colour, the intensity is proportional to the brightness as perceived by the eye, and also to its heating effect.

The amount of light received on any area varies inversely as the square of the distance from the source of light. This can be demonstrated by using a simple piece of apparatus—the "grease-spot photometer"

It has been found that the eye is unable to estimate the ratio of the intensity of illumination due to different sources of light, but that it is a correct judge of the equality of the illumination of two adjacent surfaces. For this reason the following method of photometry depends on the equalisation of two illuminations

If a sheet of paper, having a spot of grease on it, be held up to the light, it will be seen that the spot of grease is semi-transparent, and looks brighter than the rest of the paper when viewed from the side remote from the light, but darker when seen from the other side More light passes through the region of the grease spot than through the rest of the paper, and hence when seen from the side remote from the light it looks brighter than the rest of the screen, but when looked at on the other side the spot looks comparatively dark, because a large proportion of the light incident upon it passes through and is therefore not spent in illuminating its surface If the screen be placed between two sources of light, and its position adjusted until the spot cannot be seen on either side, except by close inspection, then the screen must be equally illuminated on both sides

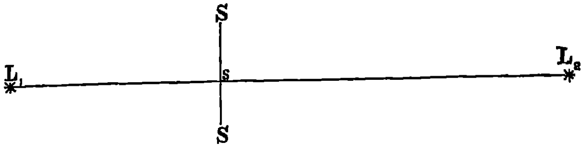

Fig 56.

If L_1, L_2, and S S (Fig 56) represent the relative positions of the lights and the screen when finally adjusted, we have—

$$\frac{L_1}{L_2} = \frac{(L_1 s)^2}{(L_2 s)^2}$$

In carrying out measurements, at least four different adjustments should be made (1) Adjust for disappearance of the spot when seen from the side of screen facing L_1 (2) Turn the screen round through 180°, and again adjust for disappearance of spot from the same surface now facing L_2 (3) Repeat (1) and (2) with the other surface of the screen

This method assumes the truth of the law of inverse squares, and the consistency of the results obtained is the best proof of the truth of this law.

211. Composition of White Light; Spectrum.—As is well known,[1] ordinary ("white") light consists of rays of different colours, and when light passes through a prism it is not only bent (refracted) from its straight course, but is separated into its different constituents, giving a many-coloured image—the spectrum. In this continuous spectrum we can recognise six principal colours (red, orange, yellow, green, blue, violet), though the number of coloured rays is infinite, and they imperceptibly merge into each other The red rays are the least refracted, the violet rays the most refracted.

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[1] See articles on Refraction, Prisms, Lenses, and Newton's Experiment, in a text-book of Physics

Beginning at the less refrangible end of the spectrum, and travelling in the direction of increasing refrangibility, we pass a group of rays known as the *dark heat rays*, which do not excite the sensation of sight Then we come to another group, *the visible spectrum*, ranging through the colours red, orange, yellow, green, blue, and violet. This group of rays, in addition to possessing heating properties, has the peculiar property of exciting the optic nerve, and thus producing the sensation of sight In this visible spectrum the intensity of the light is different in different parts, being a maximum in the yellow and gradually diminishing on both sides towards the red and violet Beyond the visible spectrum are the *dark chemical rays* These extend for a considerable distance beyond the violet, and are characterised by their power of producing chemical action in certain substances

The complete spectrum is thus made up of the *dark heat rays, the visible spectrum,* and the *dark chemical rays* The only essential difference between these is that of wave-length, which *continuously* increases from the first to the last All these rays have heating and chemical properties in different degrees and under different conditions, but only those of the visible spectrum have the power of exciting the sensation of vision

212. Effect of Light-Intensity on Photosynthesis.—It is easy to show that the rate at which a green leaf makes starch varies according to the intensity of the light. In weak light no starch is formed, and this is also the case when the light is too intense, but between the two extremes the amount of starch formed corresponds roughly with the light-intensity In most plants the optimum intensity is that of bright diffuse daylight.

It must, however, be remembered that the leaves are never all equally illuminated, and even when a plant with close foliage is exposed to bright sunlight, the average intensity of the light received by the leaves as a whole may not be greater than that of bright diffuse daylight Hence the plant can afford to risk slight injury to the more exposed leaves, in order that the rest may be able to assimilate more actively. Similarly, plants with thick fleshy leaves or green stems prefer bright sunlight because otherwise the inner assimilating layers only receive very weak light.

A certain amount of the light is absorbed by the medium through which it passes, and this loss is very great in passing through clouds, through the smoky air of towns, or through water Seaweeds and fresh-water plants can not exist below a certain depth (about 400 yards), because insufficient light reaches them

The intensity of the light is also affected by the angle at which the sun's rays strike the earth, being greatest when the sun is overhead and least when it is on the horizon This effect is, of course, due to the absorption of the light-rays by the earth's atmosphere. Owing to the longer days during the summer of temperate regions, however, plants actually receive more light per summer day than they do in the twelve hours' day of the tropics

In most plants, even shade-loving forms, photosynthesis stops when the light-intensity is reduced to 001 that of sunlight, in sun-loving plants the minimum is reached long before this

(*a*) Cover half of a leaf with thin paper, or a piece of ground glass, and expose it to light, test for starch and note result. Compare the colour, after testing with iodine, with that of an uncovered leaf on the same plant

(*b*) Place some healthy cut branches of Elodea or other water-plant under water, and select one which gives a good stream of oxygen-bubbles (fairly rapid and constant) from its cut end. Count the time required for, say, 10 bubbles to be given off, and repeat the counting several times till you get a fairly constant result Then remove the jar into the shade, or cover it with a sheet of thin white paper to weaken the light, and take times as before, noting the change in the rate of bubbling

(*c*) Cover the jar containing the water-plant with a black cloth except at one side, and throw light on the plant by placing an incandescent gas lamp, acetylene lamp, or electric lamp at different distances from it, noting the distances and the rates of bubbling Bring the lamp into such a position that bubbles begin to come off, and count the rate;

when it becomes fairly constant, bring the lamp to half this distance from the plant and count again. Part of the effect, however, is due to the heat given out by the lamp; a flat-sided bottle, or other vessel, containing water (kept cold by constant renewal) should be used as a screen to absorb the heat

213. Amount of Light received and absorbed by the Leaf.—A leaf receives only a small proportion of the light which falls on it, even when exposed to full sunshine, the greater part being lost by reflection and absorption A smooth and shiny cuticle reflects the light, while much of it is absorbed by a thick cuticle or a dense covering of hairs In either case the result is the same, the green tissue (mesophyll) in most cases actually receives only about one-tenth of the incident light

However, in most leaves the epidermis absorbs but little of the available (*i e* unreflected) light, and, on the other hand, most of this light is used by the green tissue Thin leaves transmit a good deal of the light, but such leaves usually belong to plants which grow in shaded places, so that in any case the absorption of the light received is practically complete in most plants

Only a small proportion—probably less than 5 per cent.—of the light received by the green mesophyll cells is actually used in photosynthesis, the remainder is converted into heat and causes vaporisation of the water in the chloroplasts.

(*a*) A photographer's "exposure meter" should be used to compare the intensity of light in open and shaded places, etc This instrument, some forms of which are very cheap, consists essentially of a strip of sensitised paper and an arrangement for exposing a small piece of the paper at a time, the period of exposure in seconds being noted with a watch.

(*b*) Expose pieces of the sensitive strip to the light for 1, 2, 3, 4, and 5 seconds successively, about noon on a bright day, and note the differences in tint in the five pieces After exposure put the light-prints into a light-tight box, which should only be opened in ruby light (or gaslight if gaslight paper is used).

(*c*) Strip a piece of epidermis from a leaf, place it over the opening in the meter, and expose to sunlight

Take an exposure, for the same length of time, with the same leaf or a similar one, over the sensitive paper

Take a print by exposing the paper itself to the light.

On comparing the three prints, we get a rough idea of the amounts of light shut off by the epidermis, absorbed by the mesophyll, and transmitted through the leaf (*d*) Try leaves of different plants, especially those whose epidermis is easily peeled off, and find out, by comparing the tints of the exposed paper, the relation between the amounts of light screened off by the epidermis.

In the Sunflower the epidermis allows roughly 0·1 of the incident light to pass; the paper covered by a piece of epidermis needs to be exposed nearly ten times as long as the uncovered paper to give the same tint. The whole leaf allows very little light to pass, only about 0·005, paper covered by a leaf takes three minutes or more to acquire the tint produced by full light in one second. The mesophyll, therefore, gets 0·005 of the light which falls on the leaf.

(*e*) Make and compare "epidermis prints" and "leaf-prints" of the leaves of plants growing naturally in open and in shaded places, plants with shiny cuticle (*e.g.* Holly, Cherry Laurel), leaves with hairy covering, etc., at the same time making ordinary "light prints" as a standard.

214. Which Light Rays are concerned in Photosynthesis?—It is fairly easy to test this by comparing the effects of exposing plants to light of different colours—*i.e.* allowing only certain rays to fall upon the leaves. It is found that the rays at the red end of the spectrum are more active than any of the rest in promoting photosynthesis, and that for most plants the curve obtained when the results of experiments are plotted on squared paper shows two "humps" or maxima, the higher one being in the orange and the lower in the blue, with the lowest intermediate part (minimum) in the green.

(*a*) A rough comparison may be made by setting a plant, or a leaf with its stalk dipping into a bottle of water, in a box, one of whose sides is replaced by a sheet of *red* glass, another in a box with a side of *green* glass, another with *blue* glass. After several hours' exposure to light, test each for starch with iodine solution. However, coloured glass is hardly ever pure, in the sense of allowing only rays of one colour to pass through it. This can easily be seen by testing coloured glass with a spectroscope (an excellent direct-vision spectroscope can be had for 25*s.*), or with a lantern and prism.

* (*b*) A better method is to use a pair of double-walled bell-jars, the space between the two walls being filled with a coloured solution. One should be filled with watery solution of potassium dichromate, the other with watery solution of copper sulphate, to which ammonia has been added. The first solution allows red and orange rays to pass through, the second one blue and violet rays. In this way we can at least divide the spectrum into a red-end half and a blue-end half. Set each bell-jar on a folded cloth, or in a saucer of dry sawdust, so as to

shut out any white light, place under each a plant in a pot or a seedling that has been dug out and had its root set in a bottle of water Set both bell-jars in diffused light; in direct sunlight the temperatures in the two would not be the same (why?) The plant in the red-orange light will be found after exposure to light (let the experiment last for two days) to have formed abundant starch, that in the blue-violet light will be almost free from starch.

(*c*) Watch the bubbles of oxygen arising from a submerged water-plant, and time the rate of bubbling When this is fairly regular, cover with the blue bell-jar, and notice that the bubbling becomes slower after a short time After about five minutes (take several readings during this time) take off the blue jar and put on the red-orange one, taking records of the rate of bubbling as before, noting the increase in red-orange as compared with blue-violet light

215. Chlorophyll.—Since only the green parts of plants can carry on photosynthesis and the green colour is due to chlorophyll, it is necessary to study the properties of this substance.

Chlorophyll is a colouring substance, or pigment, of a complex nature, its composition is not yet fully known It contains magnesium (and, according to some, phosphorus) in addition to carbon, hydrogen, oxygen, and nitrogen. It is probably a mixture of several pigments, but these, which can be separated artificially by treating a solution of chlorophyll by reagents, are probably products of decomposition

In nature, chlorophyll is readily decomposed by bright light, and it probably undergoes continuous changes, being built up as rapidly, in ordinary conditions, as it is decomposed. It is a fluid or semi-fluid substance, produced in, and held by, the special masses of protoplasm called chloroplasts The chlorophyll present in a chloroplast only forms about 0 1 per cent of the latter's substance

Chlorophyll can be extracted by means of alcohol, ether, chloroform, etc A solution of chlorophyll is fluorescent—it is green by transmitted light, dark red by reflected light When the solution is held against the light and examined with a spectroscope, or placed in the path of a beam of light, which is then passed through a prism, the spectrum shows dark bands, in the red, blue, and violet regions especially, the band in the red is very marked, appearing even if a weak solution is used. These dark bands (also seen on examining a thin green leaf with a spectroscope) are of course due to the *absorption* by the chlorophyll of these rays of light, the other rays being allowed to pass through the leaf. The **absorption spectrum** of chlorophyll agrees roughly with the results obtained by exposing plants to red light, green light, blue light, etc

* (*a*) Extract chlorophyll from green leaves (*e g* Bean, Grass, almost any leaves will do, but leathery ones should be chopped up) by boiling them in water, draining off the water, and covering the leaves with alcohol, Then place the dish containing the leaves and alcohol in the dark; light destroys the colouring matter in the solution Filter the solution, and place it in a corked bottle

* (*b*) Notice the colour of the filtered extract by holding the bottle up to the light, and by holding it against a black surface; it is green by transmitted light, red by reflected light Obtain a continuous spectrum on a screen by fastening on the lens of an optical lantern a card with a vertical slit, and holding a prism in the path of the light Hold a test-tube of alcoholic chlorophyll-solution against the slit, and notice that the colours in several parts of the spectrum are replaced by dark bands The most prominent dark band appears in the red part, but if the solution is strong bands will also be seen in other regions of the spectrum Try the effect of interposing pieces of glass of various colours, or bottles containing solutions of dichromate of potash and of copper sulphate In each case certain rays of light are stopped, that is, *absorbed*, and *the places of these rays in the spectrum are occupied by dark bands*, that is, by darkness

We see now that chlorophyll absorbs certain light-rays, allowing the rest to pass through it, and we may conclude that these absorbed rays in some way supply the energy which is needed in carrying on the work of photosynthesis A direct-vision spectroscope will show the absorption bands, especially that in the red part of the spectrum. A very useful additional piece of apparatus is a wedge-shaped bottle ("indigo prism") by means of which one can examine different thicknesses of the solution.

(*c*) It will be noticed that the extreme end of the red region (that nearest the invisible infra-red) is not absorbed by the chlorophyll solution If you hold up to the light a thick layer of strong leaf-extract (using the thick end of an "indigo-prism" or a flat-sided glass vessel) you will find it appears red instead of green

(*d*) Place some leaf-extract in a test-tube, dilute with a few drops of water, then add benzol, shake, and allow to settle The benzol, which floats above the alcohol, dissolves out a bluish-green colouring-matter, leaving a yellow substance dissolved in the alcohol. These two pigments present in the extract can also be separated by using ether or olive oil instead of benzol Find out, by using the spectroscope, or lantern and prism, which light-rays each of these substances absorb.

* (e) Fill three test-tubes with leaf-extract, cork them, and place A in sunlight, B in diffused light, C in darkness. Carefully boil some extract in a fourth test-tube (D), and place it with A in sunlight Notice, after a day's exposure, that A becomes brown, C is unchanged, while B and D are only slightly changed, the absence of oxygen in D hinders the destructive effect of light.

(*f*) Add some 10 per cent. solution of copper sulphate to some leaf-extract in two test-tubes; a copper compound is produced which is not red by reflected light, and which is not destroyed by light. Verify the latter point by placing one tube in sunlight, the other in darkness, in each case with a tube of ordinary leaf-extract for comparison.

216. Under what conditions is Chlorophyll produced?—We have seen that seedlings grown in darkness differ from those grown in the light in several respects. In most Flowering Plants chlorophyll is not formed in darkness, the chloroplasts are present in the cells of the stem and leaves of darkened seedlings (or of the shoots produced, say, by a potato-tuber kept in darkness), but in the stems the chloroplasts remain colourless, while in the leaves they become yellow Hence the stems remain white and the leaves turn yellow The yellow colour of the leaves is due to the presence of a pigment called **etiolin,** developed in the chloroplasts instead of chlorophyll, and the plant is said to be etiolated

If, however, we sow Pine seeds in darkness, we find that the cotyledons of the seedlings turn green Chlorophyll is also produced in the new growths formed by Mosses, Liverworts, most Cacti, and some other plants, when kept in darkness. Young Fern plants and Sycamore seedlings are further exceptions to the general rule that **chlorophyll is only produced in the light.** In any case, an ordinary green plant—one which can only manufacture its food from carbon dioxide, water, and salts—merely keeps on growing in darkness until its store of already manufactured food is used up, all the time losing in dry weight (Art 141)

It is easy to prove that chlorophyll is formed in light too weak to allow of photosynthesis. It is produced in shaded places with light-intensity of less than 0 001, though very few flowering plants can thrive in such feeble light, *e g* in dense Beech woods.

What other conditions, if any, are essential (in addition to light) for the formation of chlorophyll? It is easy to discover by experiment whether warmth, oxygen, and carbon dioxide, for instance, are required The presence of *iron* is essential, but it is not so easy to prove this; sometimes one comes upon a case in which the leaves are pale and sickly (*chlorotic*) owing to lack of iron, and can cause the production of chlorophyll by adding iron to the plant's food (e g in water-cultures, Art 230) or by applying a weak solution of an iron salt to the leaves with a camel-hair brush

* (*a*) Grow seedlings, e g Cress or Mustard, in darkness, then place some of them in a good light, close to a window, and note the time required for the production of a distinct green colour. Place the others in a dark part of the room, and when they have become green test the leaves for starch These observations will show that (*a*) a green tinge, due to formation of chlorophyll, may be developed in an hour, or less, in good light, (*b*) light too weak for photosynthesis is strong enough for the production of chlorophyll

(*b*) Sow in the same pot or box some seeds of Pine and of Bean or Pea, keeping them in darkness, and compare the colour of the Pine-seedlings with that of the others

(*c*) Place some etiolated seedlings (Cress, Mustard, Bean, etc) in a bottle or small glass jar, cover with a glass plate, and set it in a larger jar half filled with water Keep the water at 30° C. In a similar apparatus keep some of the seedlings in cool water, or water kept at 10° C, by adding bits of ice from time to time Compare the depth of the green colour developed in the two sets of seedlings after an hour or two of exposure to light.

* (*d*) To show that oxygen is necessary for the formation of chlorophyll, fill a test-tube with water, invert it in water, and pass under its rim some etiolated Mustard seedlings Though exposed to light, the seedlings do not become green, owing to lack of oxygen. Another method is to place heavier seedlings—e g Bean, Pea—in a glass jar and cover it with water. In each case similar etiolated seedlings should be placed on wet blotting-paper at the bottom of a jar, whose mouth must of course be left open

217. What is the Function of Chlorophyll?—This is a hard question to answer, except in a very vague manner We know that the waves of electrical energy, which can produce formaldehyde from carbon dioxide and water, are much longer than the light-waves in the red end of the spectrum and that red light is nearly as efficient as white light in the process of photosynthesis We know also if a leaf is covered by another leaf, or by a solution of chlorophyll, it manufactures little or no starch

As a working theory, one might infer, from the known facts, that the function of chlorophyll is to convert light energy into electrical energy, by increasing the wave-length so as to transform the relatively short waves of light into the much longer waves of electrical energy. If this be so, one can understand why the longer light-waves (red) are so efficient in promoting carbon-assimilation

218. Etiolation.—The effects of darkness on a green plant in producing starvation and loss of dry weight have already been studied (Art 141). Apart from these effects and the non-production of chlorophyll, various changes of form and structure are produced by darkness.

The stem-internodes and the leaf-stalks (if the plant has stalked leaves) are unusually long, giving the plant a "drawn" appearance In this way there is a chance of shoots reaching the light, as, *e g*, in seedlings smothered by other plants In etiolated plants, also, the leaves remain small and scaly, there is a great development of soft tissue and a meagre formation of hard woody tissue Large leaves would be useless in darkness; we might say, therefore, that the plant devotes all its energy to the formation of long "internodes" which may be of use to it Many examples of etiolated plants will readily occur to the mind of the student —*e g.* celery (leaf-stalks), grass covered by a roller or a board

A plant which is normally green must of course have a reserve store of food to draw upon in order to grow in darkness at all

* Grow in darkness (in each case with plants of the same kind grown in light for comparison) various plants which have a good store of food in their seeds or in such storage-organs as bulbs, corms, tubers Sow seeds of Broad Bean, Runner, Maize, Wheat, plant Potato-tubers, corms of Crocus, bulbs of Onion, Tulip, Narcissus, etc Also compare the growth in darkness and in light of plants which normally have a tufted or rosette habit (*e g* Crassula, London Pride, Daisy) and note that in darkness the internodes become elongated

219. The Main Function of the Leaf is to act as a laboratory for the manufacture of organic food from the carbon dioxide of the air and from the water absorbed by the roots. To carry out this process energy is necessary, and this energy is supplied by the light which the green chloroplastids absorb During the process more complex substances such as sugar are formed, and a corresponding amount of energy is stored up in this manner. At the same time a volume of oxygen gas is liberated, equivalent to the amount of carbon dioxide assimilated Hence green plants exposed to sunlight tend to purify the air rendered foul by the breathing of animals.

When a plant is burnt, oxygen is consumed and carbon dioxide and water produced, while the stored energy is liberated again in the form of heat. This energy was stored up in latent form during the assimilation of carbon dioxide, and it really represents that portion of the sunlight absorbed by the plant, which was utilised in the process, and which provided the energy necessary to produce a chemical change of this kind. Coal consists of the remains of plants of past ages, and hence, when a piece of coal burns, the heat and light which are liberated simply represent so much sunlight which has lain dormant for millions of years.

220. The Store of Carbon Dioxide in the Atmosphere.—Enormous quantities of carbon dioxide are absorbed by green leaves from the air, although the latter usually contains not more than 0.03 to 0.04 per cent. of this gas. A large Sunflower leaf may absorb, during a single hour's exposure to sunlight, the carbon dioxide contained in many cubic feet of air, making about 2 grammes of starch per hour per square yard of surface.

About half of the dry weight of a plant consists of carbon, and the 4 litres of carbon dioxide contained in 10,000 litres of air contain only 2 grammes of carbon. A tree having a dry weight of 5,000 kilograms must therefore (to obtain its 2½ million grammes of carbon) deprive 12 million cubic metres of air of their carbon dioxide. But the atmosphere contains an astounding amount of carbon dioxide, which is placed at the disposal of plants owing to its uniform distribution by diffusion.

The actual supply of carbon dioxide in the air is estimated at 3,000 billion kilograms, containing 800 billion kilograms (about 800 million tons) of carbon, which would be sufficient for the earth's vegetation for several years, even if the supply were not being continually renewed by the respiration and decomposition of organisms, by processes of burning, etc. Since an adult breathes out daily more than 400 litres of carbon dioxide the 1400 millions of human beings in the world give to the air annually about 100 billion kilograms of carbon. The amount of coal burnt annually has been estimated at 400 billion (400,000,000,000) kilograms, yielding to the air over 300 billion kilograms of carbon (coal contains about 80 per cent. carbon). Even larger amounts of carbon dioxide are doubtless produced by the Bacteria of the soil.

221. How Carbon Dioxide enters the Leaf.—In a seaweed or a submerged flowering-plant carbon dioxide is absorbed, and oxygen given out, by diffusion through the whole surface of the plant In the case of an ordinary plant with stomate-bearing green organs, the gaseous exchanges [1] between the atmosphere and the plant's tissues take place through the stomates almost exclusively The stomate-bearing leaf is a much more efficient organ of gaseous exchange than it would appear at first sight

The actual opening of a stomate is only about 0 0002 sq mm.—small enough to hinder the entrance of dust or water. The stomates are very numerous, a Sunflower leaf, for example, has about 12 millions A square millimetre of Broad Bean leaflet gave, as the average of several counts, 90 stomates on the epidermis and 140 on the lower; a large leaflet, with area about 20 sq. cms, therefore has nearly half a million stomates Still, the total area of the air-openings is only about 0 01 of the total leaf-area

It has, however, been found that the rate of diffusion of gases through a plate with small openings is much greater than through a single opening of the same total area, and that when the small openings are placed about ten times their diameter apart the rate of diffusion is as rapid as when no partition is present These requirements are met by the size and the distribution of the stomates on a leaf, and a given area of a leaf has been found by experiment to absorb two-thirds the amount of carbon dioxide taken up in an equal time by the same area of potash solution exposed freely to the air

222. What becomes of the Starch formed in the Foliage-Leaves?—Is it absorbed by the plant, like the starch stored in the cotyledons of the Bean? If so, we ought to find less starch in the leaves in the morning than in the evening, since the leaf cannot make more starch until it is again exposed to light

* (*a*) Remove some leaves from a plant in the early evening (an hour or two before sunset) and place them in alcohol. Early next morning remove some more leaves from the plant, and also cut out differently shaped

pieces from some of the leaves and place them in alcohol overnight; then compare their starch-test with that given by the rest of the leaf the next morning. The starch formed in the leaf during the day is found to have disappeared, more or less completely, in darkness

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[1] These exchanges are (1) entrance of carbon dioxide and escape of oxygen, (2) entrance of oxygen and escape of carbon dioxide, (3) escape of water vapour, in the processes of Carbon-assimilation, Respiration (Ch VII), and Transpiration (Ch VIII.) respectively

* (b) Would the starch have disappeared had the leaves not been left on the plant? Repeat the experiment, but cut some of the leaves off, set them in a tumbler with their stalks under water; cut pieces out, test them for starch, then test the rest of each leaf in the morning

223. How does Starch disappear in Darkness?—We saw that the starch stored in the Bean cotyledons is on germination converted by the action of a ferment (diastase) into *sugar*, which is soluble in water and therefore able to travel by diffusion to the growing parts of the young plant and supply them with food. We have seen that the leaf when exposed to light produces starch, which disappears during the night, and if we cut out small pieces from the same leaf every day and tested them, we should find that the alternate production and disappearance of starch go on day after day By cutting out pieces of leaf of a certain area, drying them and weighing, we should find that the dry weight of the leaf is increased at the end of a sunny day, that it decreases after some hours of exposure to darkness, increasing again on exposure to light These facts suggest that the starch formed in light is digested and carried away during darkness, and we find that the leaf-cells produce *diastase* just as do the cotyledon-cells in the Bean seedling

Keep a plant in darkness for two days, then expose it to sunlight for several hours Remove some leaves, dry them in a slow oven (or on a sand-bath), then powder them and let them soak in cold water for about half an hour Filter the extract thus obtained, and try its effect on starch-paste, testing with iodine, and later with Fehling's solution. An extract of leaves of Tropaeolum or of Broad Bean, made in this way, quickly converts starch into sugar, try these and other plants

QUESTIONS ON CHAPTER V

1 What differences exist between the cotyledons and the foliage-leaves of the Broad Bean? How may these differences be accounted for?

2. How could you prove that a leaf has air-spaces inside it and air-pores on its surface?

3 Describe the structure of a typical foliage-leaf

4 How could you prove that a green leaf makes food when exposed to light?

5 Under what conditions is starch formed in the foliage-leaves of an ordinary land plant? Give experiments in proof of each statement

6 What is a stomate, and how does it work? Why do people often syringe or sponge the leaves of plants grown indoors or beside a dusty road?

7 To what substance do the green parts of plants owe their colour? State and explain the nature of the work which only the green parts of plants are able to perform

8 Explain how it is that a green plant cannot carry on its nutrition in darkness.

9. What constituent of plant food is obtained from the atmosphere? What changes do plants affect in it? Describe an experiment to demonstrate this.

10 What is meant by the term Photosynthesis? What is the first *visible* (solid) result of this process, and how would you detect it in a leaf?

11 What gases would you expect to find in the air of a closed glass vessel exposed to light before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. How could you measure the quantity of each gas?

12 Two leaves, while still attached to the plant, are kept in the dark for twenty-four hours, then one is exposed to sunlight for some hours, while the other still remains in the dark By what after-treatment would you distinguish between the two? Explain your exact procedure and the reasoning on which you base your conclusions

13 Explain as fully as you can how it is that the guard-cells of a stoma are enabled to alter the size of the aperture between them

14 What is the importance of carbon to a plant? From what source does a green plant get its carbon, and how is it assimilated?

15 What do you consider the essential characters of the foliage-leaves of a green plant—*i.e.* the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

16 On what law does the intensity of light depend? How does light-intensity affect Photosynthesis?

17. What is meant by Refraction? What is a prism, and how could you prove by its use that white light consists of rays, having different colours?

18 Describe the continuous Spectrum. How is the appearance of the spectrum affected by an extract of chlorophyll being placed between the prism and the screen on which the spectrum is received?

19 What is the function of Chlorophyll? Under what conditions is it formed, and how does it occur in the plant?

20 What is meant by "the absorption spectrum of chlorophyll," and what do we learn from it?

21 Explain the term Photosynthesis. What gases would you expect to find in the air of a closed glass chamber exposed to the sun before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. Explain briefly how you would attempt to measure the quantity of each gas present in the mixture

22 Bubbles of gas arise when a green water-plant in a bowl of ordinary tap-water is placed in sunlight What is this gas, and how is it produced? Give as full an explanation as you can of the effect of (*a*) replacing the tap-water by previously boiled water, (*b*) introducing lumps of ice into the original bowl of water.

23. What process is meant by the term Photosynthesis? State as briefly as possible the conditions necessary for such a process Describe accurately an experiment you have seen which demonstrated that a plant was carrying on the process

24 Describe any experiments which throw light on (*a*) the passage of fluids through membranes by osmosis, (*b*) the passage of gases by diffusion through small openings What have these experiments to do with plant life?

25 Describe as many experiments as possible showing the effect of temperature on the physiological processes of plants

26 Sketch a course of work on a green leaf for an elementary class, which is not provided with microscopes

27 Describe the minute structure of a small bit of a green leaf Show that it is specially fitted for absorbing and liberating certain gases.

28 A seed (*e g* a Bean) is germinated in a dark cupboard. Describe the seedling plant developed under these conditions, and point out in what respects it differs from a plant grown in the light

29. How would you obtain, and prepare for examination, living, under the microscope, the green cells of a foliage-leaf? Draw carefully, and describe in detail, the structure of such a cell, naming the different parts, and mentioning, so far as you can, their uses.

30. What conditions are essential in order that a green leaf may form starch? Give an account of the experimental evidence on which your answer is based.

31. Explain as fully as you can the reasons for the lanky appearance exhibited by many plants when grown in the shade of trees.

32 To what substance do the green parts of plants owe their colour, and what is the use of this substance to the plant?

CHAPTER VI.

ASH-ANALYSIS AND WATER-CULTURE

224. The Food Materials of a Green Plant.—If we make a chemical analysis of a plant—an analysis of the gases given off, and the residue or ash left behind on burning the plant—we find the following chemical elements. carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, iron, sodium, silicon, and chlorine; traces of other elements are sometimes present Of all these elements, only the first six actually enter into the composition of the living substance (protoplasm) of the plant It is evident that all the elements found in the plant must enter it in the food materials absorbed. All the carbon required by an ordinary green plant comes from the carbon dioxide of the air, which is absorbed by the green parts of the plant, while the other elements are absorbed by the roots, usually in the form of nitrates, sulphates, phosphates, chlorides, and silicates of potassium, sodium, calcium, magnesium, iron, and other metals.

225. Water, Carbon, and Ash in Plants.—In several of our experiments we have seen that water is present in fresh plant-bodies, even in "air-dry" parts like seeds as sold in shops, and that the water can be driven off by drying plants in an oven without charring them. In woody parts the percentage weight of water is about 50, in herbaceous parts (*e.g* fresh leaves or whole seedlings) about 75, in fruits and in fleshy plants (*e.g.* Stonecrop) from 85 to 95, and in water-plants and Algae from 95 to 98. The residue in each case—the dried substance—gives the "dry weight"

When the dried parts are burnt, the organic substances of which they largely consist are converted into inorganic substances, chiefly carbon dioxide and water, which escape during the process of burning, the nitrogen, as well as the carbon and hydrogen, disappears into the air when the plant is burnt If the dried substance is charred instead of being entirely burnt, we get charcoal, and if we collected the carbon dioxide given off in complete combustion we should find that a large percentage of the dry weight is represented by carbon—as much as one half

The incombustible residue, or ash, represents the mineral substances, but in the process of burning these substances undergo changes, so that they occur in the ash in chemical combinations different from those present in the fresh plant-body

226. Analysis of Plant Substance.—To make an exact chemical analysis of plant-substance requires considerable skill in qualitative and quantitative methods of chemistry But it is fairly easy to get a rough idea of the composition of plants by simple experiments

* (*a*) Weigh some freshly picked leaves and record the weight Let them lie in a dry place until they become apparently dry ("air dry") and weigh again From your work on transpiration you will know that the loss of weight is due to loss of water

* (*b*) Dry the leaves in an oven and weigh them twice or thrice until they show no further loss of weight In this way you get the percentage weights of water and of dried substance As a check or "control," heat some other "air-dry" leaves gently in a test-tube and note the deposition of water in the cooler upper part of the tube. this represents the "hygroscopic" water which is driven out by heating

* (*c*) Dry and weigh a porcelain crucible, place in it the oven-dried leaves, and heat thoroughly. The dry material chars and may flame for a time while burning; in ten minutes or so it is reduced to fine ash Find the weight of the ash, weighing the crucible and its contents twice or thrice until no further loss occurs. To ascertain roughly the amount of carbon, heat some weighed oven-dried leaves in a weighed crucible, after covering them with a weighed quantity of dry sand, after about ten minutes' heating turn out the contents and find the weight of the charcoal

227. The Ash Constituents.—The amount of the ash increases with the age of the plant (why?) It also varies in the different parts of the same plant at different stages in its growth and life-history.

The following table gives, for several common plants, the approximate percentage weights of (1) the ash in the plant's dried substance, (2) the metallic oxides, the acids, and chlorine in the ash itself

Plant	Ash in 100 parts of dry substance.	100 parts of Ash contain								
		Potash.	Soda.	Lime.	Magnesia.	Iron oxide	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
Red Clover	6·8	31	0·2	35	11	1	10	3	2	4
Wheat (grain)	2	30	2	3	10	1	46	0·4	2	0·2
,, (straw)	5	14	1·4	6	2·5	0·6	5	2·5	72	2
Rye (grain)	2	32	1·5	3	11	1·2	48	1·3	1·4	0·5
,, (straw)	4·5	22	1·7	8	3	2	6	4·3	49	2
Pea (seeds)	2·7	43	1	4·8	8	0·8	36	3·4	1	1·6
,, (straw)	5	23	4	37	8	1·7	8	6·3	7	5·6
Potato (tubers)	3·8	60	3	2·6	5	1	17	6·5	2	3
Grapes	5·2	56	1·4	10·8	4	0·4	15	5·6	2·7	1·5
Apples	1·5	36	26	4	9	1·5	14	6	4	—
Tobacco (leaves)	17	29	3·2	36	7·4	2	4·7	6	5·8	6·7
Cotton (fibres)	1·1	40	13	17·5	5·4	0·6	10·6	6	2·4	7·6
Spinach	16·5	16·5	35	12	6·3	3·3	10·2	6·8	4·5	6·2
Horsetail	27	8	0·6	8·6	1·8	1·4	1·4	2·8	71	5·6
Almond seed	4·9	28	0·2	8·8	17·6	0·5	43	0·4	—	—

Note the striking difference between the seeds and the straw (stalks and leaves) of Cereals and Leguminous plants in the proportion of more important (*e g* magnesium) and less important (*e g.* silicon) elements

228. Ash Analysis.—The chief elements to be tested for, in analysing the ash of plants, are calcium, potassium, magnesium, phosphorus, sulphur (the two latter being present as acids) The ash should *not* be heated so strongly as to make it burst into flame.

(*a*) Is the ash soluble in (1) water, (2) dilute hydrochloric acid, (3) strong hydrochloric acid? Find out in each case by boiling some of the ash in a test-tube with water or acid, allowing the undissolved part to subside and evaporating some of the liquid, or heating it to dryness, on a watch-glass or evaporating-dish The insoluble residue, after treatment with strong acid, contains chiefly silica.

(*b*) Place about 10 grammes of ash in a 500 c c flask, moisten it with a small quantity of strong nitric acid, then add about 20 c cs. strong hydrochloric acid and heat on a tripod (or "digest" it for half an hour on a water- or sand-bath at boiling-point) Rinse the contents of the flask into an evaporating basin and heat to dryness Moisten the residue with strong hydrochloric acid, add about 200 c cs of water, and filter Make the filtrate up to 600 c cs with water and divide it into four parts

(i) To one part add, in a large test-tube, some barium chloride solution The finely-divided white precipitate (barium sulphate) indicates the presence of **sulphur** (as sulphuric acid) Verify this by mixing some dry ash with carbonate of soda, heat on charcoal with the reducing blowpipe-flame, and (1) put a few drops of dilute hydrochloric acid on the fused mass (the sulphuretted hydrogen given off is easily recognised by its odour), (2) put a little of the mass on a silver coin and add a drop of dilute acid (a black stain of silver sulphide is formed) These "dry" tests may fail, however, if but little sulphuric acid is present.

(ii) To some ash-solution in a test-tube add an equal bulk of strong nitric acid, then three or four times its bulk of ammonium molybdate A yellow precipitate indicates presence of **phosphorus** (as phosphoric acid)

(iii) To test for **iron**, add potassium ferrocyanide a dark blue precipitate (Prussian blue) is produced.

(iv) It is necessary to remove the phosphates from the ash solution, as follows Neutralise with ammonia, then add acetic acid till the solution is distinctly acid again, and then ammonium acetate in excess Now add ferric chloride till no further buff-coloured precipitate (ferric phosphate) is produced and the solution becomes red (owing to ferric acetate) Boil the solution till it is colourless, filter, and reject the precipitate

To the solution thus obtained add ammonium chloride, ammonia, and ammonium carbonate, a white precipitate indicates the presence of **lime.** Filter, and to the filtrate add sodium phosphate, a white precipitate (often formed only after shaking the liquid and letting it stand for some minutes) shows that **magnesia** is present.

Filter, evaporate the filtrate to dryness, and test the residue for soda and potash. Add a few drops of platinic chloride to the residue, evaporate again, then add some alcohol; a yellow crystalline precipitate shows that **potash** is present Or dip a clean platinum wire into hydrochloric acid and hold it in a Bunsen or spirit-lamp flame until it no longer colours the flame yellow (owing to presence of soda). Then dip the wire, moistened with hydrochloric acid (strong) into the residue and put it in the flame **Potash** turns the flame *violet*, but if the *yellow* (**soda**) colour is too strong look at the flame through a *thick* piece of blue glass the soda colour is cut off and the reddish-violet potash flame is seen.

If you are working in a chemical laboratory, you should try to make rough quantitative analyses of the ash of a few plants, using the methods given above, with the help of a book on Quantitative Analysis

229. Essential Elements of Plant-Food.—All the elements named in Art 227, and several others, occur in the composition of plants and their food In fact, nearly all the chemical elements known to occur in soil, water, and air have been detected in analyses of plants It has been found by experiment, however, that for most green plants the **essential elements**—*i.e* the elements absolutely necessary for healthy growth—are **carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, potassium, magnesium,** and **iron.**

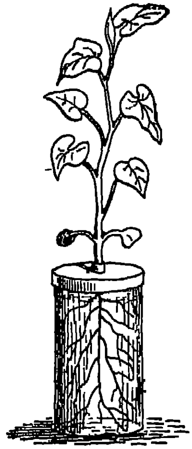
Fig 57 —A Plant of Buckwheat grown with its Roots in a Culture-solution

230. Water Culture.—It has long been known that a plant can be grown in water containing salts in which all these elements are present with the exception of *carbon.* That carbon is essential is easily proved, as we have seen, yet this element need not be present in the solution supplied to the roots. That all the other elements are essential, and must be supplied to the roots, has been shown by the method of **water culture.** Several plants of the same species are grown in glass jars (Fig 57), their roots dipping into a culture solution With most plants there is healthy growth only if the solution contains *potash, lime,* and *magnesia,* combined with *nitric, phosphoric,* and *sulphuric* acids, together with a trace of an *iron* salt.

*** 231. Experiments with a complete Culture Solution.**—Get some large glass jars, each holding at least a quart, for water-culture experiments. Sachs' solution consists of 2 grammes of potassium nitrate, 1 gramme each of sodium chloride, calcium sulphate, magnesium sulphate, and calcium phosphate, and a drop or two of iron chloride (or iron phosphate) to 2 litres of distilled water. Knop's solution, which is perhaps better, consists of 2 grammes of calcium nitrate and 0·5 gramme each of potassium nitrate, magnesium sulphate, and potassium phosphate, with iron as before, in 4 or 5 litres of water. Perhaps the best plan is to get 4 oz. of calcium nitrate and 1 oz. each of potassium nitrate (saltpetre), magnesium sulphate (Epsom salt), and potassium phosphate, and powder these salts to make them dissolve more readily. These quantities will be sufficient for 32 gallons of culture solution; but the latter should be made up as required, so that the above quantity of each salt should be subdivided according to the volume of solution required each time.

Another method is to prepare strong solutions of the salts and dilute them as required. Make (1) a solution containing 2 grammes $Ca(NO_3)_2$, 1 gramme KNO_3, and 1 gramme KH_2PO_4 to every 100 c.cs. of water; (2) a solution containing 0·5 gramme $MgSO_4$ to every 100 c.cs. of water.

Grow seedlings of Bean, Pea, Maize, Buckwheat (these answer well, but other plants should be tried, different plants each time you start a series of cultures) until the roots have grown a few inches long, then fix each seedling into a cork or a wooden cover. The cork or cover should have a hole in the centre for the plant, a slit somewhat narrower than the hole running to the edge of the cover (so that the plant can be removed easily when necessary), and another hole for a stick to tie the plant to (Fig. 58). Take care to keep the cork, or wooden cover, as well as the part of the plant which is in contact with it, quite dry; most failures in water-culture are due to "damping off" at this part (caused by fungi). If a stick is used to support the plant, there is no need for any packing material. Cuttings of Willow and other trees may be used as well as seedlings.

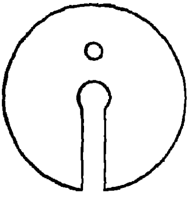

Fig. 58.

Darken the roots by covering the jars with black cloth or paper; add water each day to replace that lost by evaporation and transpiration (using a funnel, and not letting the cork, or wood cover, get wet). Once a month take the plant out, wash its roots gently in a basin of water, pour out the culture solution, and let the plant remain with its roots in plain water for two days before placing it into fresh culture solution.

The culture solution should not be alkaline, or the roots suffer; if it turns red litmus to a blue colour, add acid (*e.g.* phosphoric acid) until it gives an acid reaction.

The roots should be supplied with air; the simplest plan is to force air into the solution every day or two with a bicycle-pump or a condensing syringe. Plants in culture solutions are apt to suffer badly from lack of oxygen, the amount of which is far below that present in a well-aerated soil. If possible, use vessels of 1 gallon capacity.

*** 232. Experiments with incomplete Culture Solutions.**—Choose seedlings as nearly equal in size and general growth as possible, then place some in a complete solution, others in a solution from which one or other of the essential elements is wanting. To deprive the plant of potassium, use sodium nitrate instead of potassium nitrate, and calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting the calcium nitrate, of phosphorus by omitting the potassium phosphate; of magnesium by using calcium sulphate in place of magnesium sulphate, of sulphur by using magnesium chloride instead of the sulphate, of nitrogen by using sodium chloride and calcium sulphate in place of calcium and potassium nitrates, of iron by omitting the iron salt (which should be added in all other cases).

233. Essential Soil-Substances.—A soil must contain the same essential elements as the full culture solution in order to allow plants grown in it to come to maturity, and these elements must be in a form available for use by the plant Soil-water contains most of the essential elements in the form of dissolved compounds The composition of the water present in a soil can be learned by analysis of drainage water, and we can test soils for soluble substances by letting distilled water drain through them and then applying to it tests for the essential elements given above

* (*a*) Compare the growth of seedlings (of the same kind of plant) which have been supplied with (1) distilled water; (2) tap water, (3) culture solutions (some complete, others with one element or other omitted in each case) If you grow the plants in washed sand, water with (1), (2), or (3) daily In either case compare also with plants grown in good garden soil After, say, six weeks, dry thoroughly and weigh the seedlings, and compare their dry weights, then burn them and compare the ash weights.

* (*b*) Place some dry, fine garden soil in a funnel, plug the tube lightly with cotton-wool, and pour water slowly on the soil. Collect the first few drops that ooze through and repeat the test with diphenylamine. The presence of nitrates is shown by the production of a deep blue colouration A fertile soil always contains nitrates.

* (*c*) Continue to pour water through the soil in the funnel, and after collecting what comes through, evaporate it to dryness and compare the residue with what is left after evaporating an equal volume of the water used

QUESTIONS ON CHAPTER VI.

1 What chemical substance forms the great bulk of the weight (*a*) of a living plant, (*b*) of a plant-body after it has been thoroughly dried in an oven? If the dried body is now carefully burned and the ash collected, of what substances will it be found to consist, and what has been lost in the process of burning?

2. How would you yourself determine the percentage of water and the percentage of ash present in a plant? Name the elements most generally present in a plant, and state how you would determine which of these elements were absolutely necessary to the life of the plant

3 How would you determine the best strength for a culture solution? How would you discover if the strength of the solution was altered by the growth of the plant in it?

4 Explain how you would proceed to make a water culture Indicate the effect, on the plant, of the omission of salts containing calcium, potassium, and nitrogen respectively.

5. How are water-cultures carried on? What are the commonest causes of failure, and how may they be guarded against?

6 Pea seedlings with their roots in distilled water will sometimes grow and produce leaves and flowers. Name the elements that the plant must have obtained from some source or other, and explain how the feeding of the plant in this case must have (*a*) agreed with, and (*b*) differed from, that of a Pea seedling grown in earth

7 In what form is (*a*) hydrogen and (*b*) nitrogen absorbed by a plant?

Explain as fully as possible the part played by each of these elements in the economy of a green plant.

8 Give results of actual experiments which show that seedlings of common green plants are nourished (*a*) by air and sunlight, (*b*) by substances taken up from the ground

9 What are the essential elements of an ordinary green plant's food? In what forms are these elements obtained?

10 What is meant by "water-culture"? Name the substances which are used in making up a culture-solution for a green plant.

11. Describe the method by which the importance of the various mineral constituents of a plant's food has been most satisfactorily ascertained

12 What materials compose the food of plants? Explain the differences you have observed between the nutritive processes of a young seedling and those of an adult plant.

CHAPTER VII.

THE RESPIRATION OF PLANTS.

234. Respiration.—Every living being, plant, or animal needs a continual supply of energy, without which, for example, neither growth nor active movement is possible In the case of a machine, such as a steam-engine, this energy is derived from the burning of coal, the carbon of the coal being oxidised to carbon dioxide, and energy being liberated in the form of heat. Similar processes take place in all living beings, but here the combustion is less violent, so that the rise in temperature is never very great, and the substances consumed may be more or less complex in character (starch, oil, proteids, etc.)

Like animals, all plants respire—that is, they absorb oxygen and exhale carbon dioxide—losing carbon during the process. Germinating seeds and fungi respire as actively as do warm-blooded animals. The process of respiration is one of slow combustion, and, although the carbon is oxidised at a comparatively low temperature, enough heat is produced to keep an animal warm, or to raise the temperature of a plant by a few degrees Plants have, however, so large a surface relatively to their bulk that they lose heat very rapidly, and are usually at almost the same temperature as that of the surrounding medium.

When a green plant respires it simply consumes organic material, which it itself had previously constructed from simple compounds by the aid of the energy contained in sunlight. Thus starch is produced from water and carbon dioxide, and a certain amount of energy fixed and oxygen liberated. Then, at a later date, starch may be consumed in respiration, oxygen being absorbed, carbon dioxide and water liberated, and the "fixed" energy set free. Green plants are unable to make direct use of the energy of sunlight they absorb, but, instead, adopt this apparently roundabout method. Its utility is, however, sufficiently obvious, for if plants were directly dependent upon the radiant energy of the sun for their supplies of energy, they could only grow during the daytime, and even then the more deeply situated tissues would receive hardly any supply of energy as compared with the more external ones.

We saw that seedlings grown in darkness lose in dry weight (Art. 141). In an experiment the dry weight of 100 Wheat grains was found to be 4 grammes, that of 50 Peas 11 grammes. In each case a batch of seeds, equal in number and practically equal in weight, was germinated in darkness, and in three weeks the dry weight of the 100 Wheat seedlings was found to be 1.5 grammes, that of the 50 Pea seedlings 6 grammes.

The intensity of respiration varies greatly in different species, in different plants of the same species, and in the same plant at different stages of its life. Oily plants and shade-loving plants respire feebly, flowers and opening buds, as well as germinating seeds, respire much more actively than fully-grown roots, leaves, etc.

At about 15°C. the following plants absorb, per gramme of their fresh weight, the following volumes of oxygen in cubic centimetres:— Cacti, 3 to 25, Stonecrop, 70, Spruce Fir, 44, Broad Bean, 96; Wheat, nearly 300.

At 15°C. the volumes of carbon dioxide produced by the following, per gramme of dry weight, are:—Mustard seeds, 50 c.cs., Poppy seeds, 120 c.cs., Lilac buds, 35 c.cs., Lime-tree buds, 70 c.cs.

The spadix of *Arum* (Cuckoo-pint) was found to use up during its opening 700 c.cs. of oxygen in twenty-four hours, the volumes (in c.c.) used in the first six hours being 50, 70, 100, 140, 80, 40. A gramme of spadix substance may give out as much as 30 c.cs. of carbon dioxide in an hour, and half of the stored substance (starch and sugar) may be used up in a few hours.

The volumes of oxygen used up in twenty-four hours by the reproductive parts of flowers (anthers and pistil), taking the volume of these parts as unity, was found to be:—Wallflower, 18; Tropaeolum, 16; Cucumber (male), 11; Cucumber (female), 7.

The volumes of oxygen used by the leaves (in darkness) were (volume of leaf = 1):—Wallflower, 4; Tropaeolum, 8; Passionflower, 5; Holly, 0.9, Aspidistra, 0.5 (which partly explains why this plant withstands unfavourable conditions indoors).

235. Water produced in Respiration.—Since starch when heated gives off water as well as carbon dioxide,[1] and since respiration is essentially a process of oxidation or combustion, we should expect that 5 volumes of water should be produced for every 6 volumes of oxygen used up. In the normal respiration of most plants, the volume of carbon dioxide given out nearly corresponds to the volume of oxygen absorbed, but it is not easy to prove that the theoretical ratio holds good as regards the water produced. But even in rough qualitative experiments it is easy to show that germinating seeds in darkness lose more of their dry weight than one would expect from the amount of carbon dioxide formed, and this additional loss represents the water produced by respiration.

236. Respiration of Fleshy Plants.—Other substances besides carbon dioxide and water are produced in normal respiration, especially organic acids (malic, oxalic, etc.). In fleshy plants (succulents, *e.g.* Cacti, Crassulas, "Ice-plants") these acids are produced in such quantities that the formation of carbon dioxide may be stopped altogether for a time. The amount of acids in the leaves increases at night; in darkness these plants absorb oxygen without giving off carbon dioxide, so that the air around them diminishes in volume. These acids would injure the plant if they accumulated too much, but when a certain point is reached the plant begins normal respiration, giving off carbon dioxide, which in sunlight is at once assimilated, starch being formed and oxygen set free. Hence in the morning, when assimilation begins, fleshy plants give out more oxygen than they absorb carbon dioxide, and they will continue to give out oxygen in an atmosphere free from carbon dioxide.

Succulents reduce their rate of transpiration, on account of their habitat (see Chap. XXVII.), by having few stomates and small air-spaces, and this means a reduction in the rate of gaseous exchange and therefore in that of assimilation,

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[1] According to the following equation :—

$$\underset{\text{Starch.}}{C_6H_{10}O_5} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon dioxide.}}{6CO_2} + \underset{\text{Water}}{5H_2O}$$

hence they avoid, by their peculiar mode of respiration, the loss of carbon which takes place in ordinary plants by the setting free of carbon dioxide into the air.

237. Respiration in Oily Seeds during their germination is also peculiar While oily seeds are *ripening* (after fertilisation), the supplies of sugar they receive (through the seed-stalk) are changed to oils, and in this process more carbon dioxide is given off than oxygen is absorbed—about five times as much, for instance, in Castor Oil When the ripe seed germinates, the oils are changed into sugars.

During the first few days of germination the amount of carbon dioxide given out is less than that of the oxygen absorbed. In Linseed the ratio $\frac{CO_2}{O_2}$ for the first six days is (roughly) 0·3, 0 35, 0·4, 0 5, 0 6, 0 65. Hence these seedlings at first *increase* in dry-weight As the conversion of oils into sugars continues, the ratio $\frac{CO_2}{O_2}$ gradually approaches 1.

These results are easily explained by the fact that carbohydrates contain more oxygen than oils do.

238. Respiration affected by Temperature.—Respiration is not affected much by *light,* either by its presence or absence, or its intensity, but *heat* is of great importance The optimum temperature for respiration is nearer to the maximum than is the case with other vital processes. In germinating seeds, 10 to 20 times as much carbon dioxide is produced near the maximum temperature (35° to 45° C) as at 0° C. In Broad Bean seedlings the amounts of carbon dioxide produced at 30°, 35°, 40°, 45°, and 50° are (in milligrams per gramme of fresh weight) 550, 800, 660, 600, and 200. In sprouting Potato-tubers the amounts at 10°, 20°, 30°, 35°, 40°, 45°, 50°, 55°, and 60° are 120, 220, 460, 780, 1020, 1220, 1110, 1030, and 270 milligrams per gramme of fresh weight.

239. Respiration Experiments.—Most of the points just mentioned can be demonstrated by simple experiments. If time allows, some **quantitative** experiments should be made, *e g* with the apparatus shown in Fig 59 In any case make the following experiments —

* (*a*) Get nine glass jars of equal capacity Into 1 pour a little water Into 2 put some soaked peas, and into the others put an equal weight of the following fresh materials 3, living roots (cut from seedlings), 4, mushrooms, 5, onions sliced in half; 6, sliced carrots, 7, pieces of herbaceous leafy shoots, 8, living woody stems. In 9 put some peas killed by boiling and then washed with formalin (to prevent growth of moulds and germs) Set all the jars together, after corking them and sealing the corks with vaseline, in darkness After twenty-four hours lower a lighted taper into each jar in turn, noting the time required for the extinction of the taper in each case

* (*b*) Repeat the experiment, this time keeping the jars exposed to the light on a bright day, or for two days

* (*c*) Repeat the experiment, but instead of using the taper pour into each jar (at the end of the experiment) an equal volume of baryta-water; replace the cork, shake the jars well, and compare the degree of milkiness produced in each case Make the experiment twice—in darkness and in light.

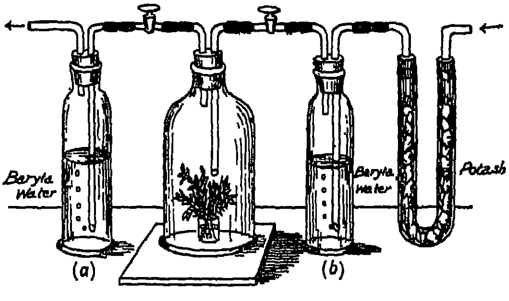

Fig 59 —The Arrows show the Direction of the Current of Air, which is drawn through by attaching an "Aspirator" (Art. 81, Fig 25) at the left of the Apparatus The two pieces of glass tubing fitted with stop-cocks may be dispensed with and clips used on the rubber tubing (shown black).

(*d*) Suspend three healthy laurel leaves by threads from the well-fitting cork of a large bottle containing lime-water, and expose them to bright light. After several hours the lime-water is still comparatively clear. Cover the bottle with black cloth, and in a few hours the lime-water will become quite milky, owing to the respiration being no longer masked by the re-assimilation of the carbon dioxide it produces

(*e*) Place some green leaves in a glass jar (Fig 59), through which a slow current of air is passed. This air is deprived of its carbon dioxide by the potash contained in the U-tube, so that the lime-water or baryta-water in both bottles remains clear so long as the leaves are exposed to sunlight or very bright daylight, whereas if the bell-jar is covered with a black cloth, the liquid in the left-hand bottle soon becomes turbid and milky.

In Fig. 59, the plant used is covered with a bell-jar standing on a glass plate, its rim being smeared with plasticine and vaseline to make the junction air-tight.

(*f*) Using the same apparatus, we can make rough **quantitative** experiments. The amount of carbon dioxide produced is determined by weighing the left-hand bottle before and after putting in the baryta-water and again at the end of the experiment. The gain in weight of the baryta-water represents the weight of barium carbonate ($BaCO_3$) produced, and from the atomic weights of barium, carbon, and oxygen we calculate the weights of the carbon dioxide and from that its volume.

A simpler plan, if the necessary apparatus and chemicals are available, is to "titrate" samples of (1) the baryta-water put in the bottles before the experiment begins, and (2) the clear baryta-water above the precipitate at the end of the experiment, using standard solutions of oxalic acid and of phenolphthalein (see books on Volumetric Analysis).

240. Comparison of Photosynthesis and Respiration.—These are, to a certain extent, antagonistic processes, the first involving a production of organic material, a consumption of carbon dioxide, and a liberation of oxygen; the second, a consumption of organic material, a liberation of carbon dioxide, and a consumption of oxygen. Photosynthesis is twenty or thirty times more active than respiration in most healthy green organs exposed to bright light and supplied with sufficient carbon dioxide, so that these parts do not appear to respire during the day-time, or at least do not evolve any carbon dioxide. In darkness, however, it can be shown that they respire only, as is the case with roots and all other not-green parts in both light and darkness.

Photosynthesis.	**Respiration.**
A feeding process, associated with building-up of plant's substance.	A breathing process, associated with breaking-down of substance.
Starch is (usually) formed.	Carbon dioxide formed.
Plant gains in dry-weight.	Plant loses in dry-weight.
Only occurs in light.	Occurs in darkness as well as in light.
Only occurs in green plants and in green parts of plants.	Occurs in all plants and all parts (except anaerobic Bacteria).
Carbon dioxide passes in, oxygen passes out.	Oxygen passes in, carbon dioxide passes out.

241. The "Balance of Nature"—Animals and non-green plants are all ultimately dependent upon green plants for their organic food In order to obtain a sufficient supply of energy, without which life is impossible, the greater part of this food is consumed in respiration, the carbon being re-oxidised into carbon dioxide, which is ultimately again assimilated by green plants

The whole series of these interchanges between the self-supporting (chlorophyllous plants and animals) and the dependent members (non-green plants and animals) of the organic world forms what is known as the "Balance of Nature" If more organic food becomes available animals and non-green plants tend to increase, and hence produce larger quantities of carbon dioxide, which favours the development of green plants. The balance maintained between the processes of respiration (in all organisms) and photosynthesis (in green organisms) keeps the amount of carbon dioxide in the air practically the same

QUESTIONS ON CHAPTER VII

1 What is meant by respiration in plants? Describe any anatomical features in one of the higher plants which are suited to facilitate the respiratory processes

2 How would you identify the gases of which the atmosphere is composed? Do you know how to determine the proportion by volume in which the two principal gases exist? Which of the gases of the atmosphere are used by plants? What differences in the constitution of the atmosphere do plants bring about under different conditions?

3 Describe and explain the various methods with which you are acquainted by means of which air can be deprived of its oxygen

4 What changes in the composition of the air are brought about (*a*) by green plants, (*b*) by animals? At what stage of its life does a plant behave in this respect like an animal? Explain the phrase "balance of nature"

5 Plants both absorb and give out carbon dioxide State precisely the circumstances upon which each process depends.

6 Give an account of the process of Respiration, and sketch apparatus by which you can investigate the gaseous interchanges associated with it What is the physiological importance of respiration?

CHAPTER VIII.

TRANSPIRATION.

242. Transpiration.—Everyone knows that a leaf, plucked from a living plant, becomes dry and withered after a time. A Bean seedling becomes limp when pulled up and allowed to "wilt," but recovers when set in water

Have you noticed that wherever plants are enclosed by glass—*e.g* in greenhouses, or bell-jars covering plants—moisture often collects on the glass? Does this moisture come from the moist earth, or from the plants, or from both? It is easy to show by experiment that a healthy and vigorous plant gives off water-vapour, which escapes chiefly from the leaves This escape of water-vapour from a plant is called *transpiration*, and the current of water which passes from roots to leaves is called the *transpiration current*.

243. The Transpiration Current.—The amount of water conveyed upwards from the roots to the leaves is often very great, the water flowing upwards at from 6 ins. to 6 ft per hour in trees (as much as 20 ft per hour in climbing plants with long slender stems, *e.g* cucumber)

If the stem of a Vine or similar plant is cut in spring, large quantities of watery sap escape from the cut end attached to the roots,[1] and if a tube filled with mercury or water is attached to this cut end, by stout rubber tubing, the escaping sap may support a column of mercury several inches high, or one of water several feet in height.

A Sunflower, 3½ ft. high and with a surface of 5,600 square ins., has been found in summer to exhale a pint of water a day, which is about a cubic millimetre from each square inch. Excessive and unchecked transpiration is, however, highly dangerous, and hence arises the importance of an impermeable cuticle, for it allows transpiration to be regulated by the opening and closing of the stomates.

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[1] This only takes place when the plant is fully charged with water. Hence, in summer, no "bleeding" is shown, although if all the leaves are removed it may commence after a longer or shorter interval.

The guard-cells collapse and close the stomates in darkness, and also where there is a deficient supply of water, or when transpiration is too active. The leaf is unable to assimilate carbon dioxide in the absence of light, so that the stomates may close in darkness without detriment to the plant, and in this way unnecessary evaporation and its accompanying cooling effect are largely avoided.

When the stomates close at night, water is still absorbed by the roots, and in this way a plant which has become wilted on a hot day recovers its turgidity at night Drops of water may be forced out of the leaves, usually through special openings (water-stomates) at the margin of the leaf A water-stomate has two guard-cells, but these remain always apart, so that the stomate does not open and close like an ordinary stomate. Water-stomates occur at the ends of the bundles (on the teeth when the leaf-margin is toothed—well seen in Fuchsia) and are connected with the bundle-endings by means of a mass of glandular tissue (water-gland) In Saxifrages there are hairs close to the water-stomates, on which lime is deposited as the excreted water evaporates In Grasses the water escapes between the ridges of the leaf and, in seedlings at any rate, from the tip of the leaf.

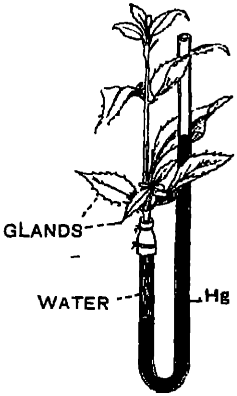

Fig 60.—Mode of demonstrating the Excretion of Fluid Water from Leaves.

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* (*a*) Cover various growing plants with a bell-jar overnight and look for water-drops excreted by the water-stomates The plants should be growing in pots, and the following will usually give good results —Fuchsia, Tropaeolum, London Pride (a Saxifrage, with chalk-glands). In a cut twig of Cherry, set in water and kept under a bell-jar, drops of water are seen oozing from the glands on the leaf-stalk.

(*b*) Cover seedlings of Wheat or Maize with a bell-jar, and note the excretion of water from the tips of the young leaves

* (*c*) Fix a cut piece of a Fuchsia into the short limb of a J-tube, as shown in Fig 60 Pour some water into the tube and then pour in mercury Drops of water are caused to escape from the "water-glands" on the teeth of the leaf-margin. A water-gland is a mass of tissue at the end of a vein, communicating with the water-stomates on the leaf-teeth.

244. Transpiration Experiments.—Does the water-vapour escape from both sides of a flat (bifacial) leaf to an equal extent? Through what channels does it pass in the leaf? Does the rate of transpiration vary, and what conditions cause it to vary? What other questions regarding transpiration occur to you, and how would you attempt to get the plant to answer your questions?

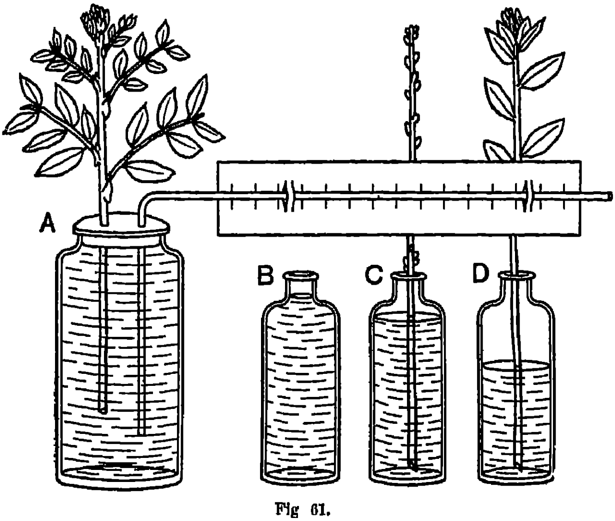

Fig 61.

* (*a*) Get three similar bottles full of water (Fig. 61, B, C, D) Into one (D) place a leafy shoot, into the second (C) a shoot deprived of leaves, and leave the third (B) as a control. See that the level of the water is the same in all three bottles at first; after some hours' exposure to light compare the amounts of water left in the bottles. Which loses most water, and which least?

* (*b*) Fix a long-stalked leaf (or the upper part of a Broad Bean or shoot, *e g.* Dead Nettle) in a card, passing the leaf-stalk (or the stem) through a hole in the middle of the card and sealing it up with putty or plasticine Place several cards, each with a leaf or shoot fixed into it, over tumblers nearly filled with water, and over each of these tumblers invert a dry empty tumbler, resting on the card Notice the drops of water formed on the inside of each empty tumbler, by condensation of the water-vapour given off by the leaves. Ascertain whether any water-vapour is given off when (1) the upper surface, (2) the lower surface, of the leaf is smeared with vaseline to block the stomata

* (*c*) Get any leaves with broad, thin blades and fairly long stalks—*e.g* Lesser Celandine, Garden Geranium [1] Place them in bottles of red ink, with the cut lower end of the stalk dipping into the ink, and note the coloration of the veins Cut a Grass shoot above the creeping stem, and try the same experiment, noticing the parallel arrangement of the veins, as indicated by the red lines which appear in the leaves in a day or two, a Maize or Wheat seedling may be used

(*d*) The sucking force exerted by the leaves can be demonstrated by attaching a leafy branch, cut under water, to a tube filled with water and dipping into a coloured solution It will be found that the latter ascends the tube even when the latter is many feet in length

Get a branch of Willow in which the young leaves have become fully expanded, and attach it by means of a piece of stout indiarubber tubing to a glass tube about 9 ins long, with the end farthest from the branch bent at right angles for about 2 ins. Arrange the branch vertically, the longer limb of the glass tube horizontally, and the short terminal part dipping into water tinged with red ink It is best to cut the branch and attach the tubing under water in a large basin, so as to prevent the entrance into the stem of air-bubbles, which would diminish the flow of water Lift the glass tube out of the water when the branch is fixed up, and notice that the coloured water soon begins to travel along the horizontal tube This apparatus may be used to roughly measure the rate of the transpiration current.

(1) Ascertain whether the flow is different on bright and on dull days, and (2) whether it is influenced by opening door and window so as to cause a draught What is the effect of smearing the surfaces of the leaves with vaseline? On different branches smear (1) the upper surfaces, (2) the lower surfaces, (3) both surfaces, of the leaves, and note the rate of the transpiration current in each case

* (*e*) A useful piece of apparatus for observations on transpiration is the **potometer.** The essential part of the apparatus is the potometer-tube (Fig 62 A), a straight tube (*a*) about half an inch in diameter with a bent tube (*b*) annealed to it about half way. The object of the branched tube is to prevent the accumulation of air-bubbles below the cut end of the shoot at *a*. Any air-bubbles passing up the narrow

tube (inserted through a cork at the lower end of the straight limb) will usually collect at *b*, and the cork at *b* is then removed and water poured in If air collects at *a*, simply turn the apparatus so that the straight limb lies horizontally above the side-limb, when the air passes up to *a*

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[1] In winter the long-stalked heart-shaped leaves of Garlic Mustard are very useful for experiments on transpiration. In spring use leaves of Lesser Celandine or Violet.

(*f*) Fix up the apparatus shown in Fig 62 B, and take readings as in the preceding experiment From the inside diameter of the narrow tube you can easily calculate the volume of water sucked along in a given time by reading from the cardboard scale and multiplying the tube-diameter by itself, by 0 8 (strictly 0 785), and by the length

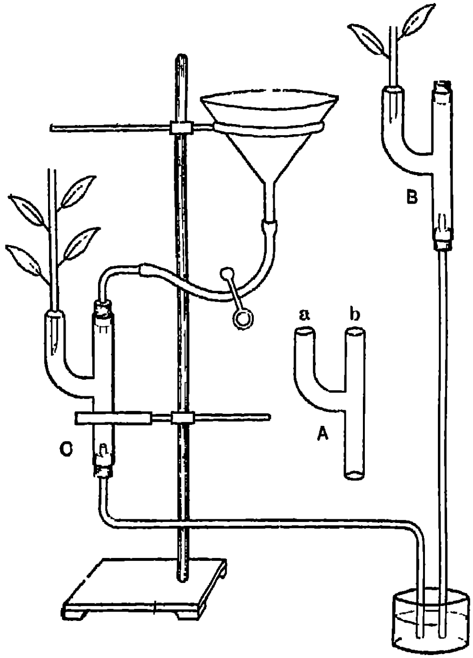

Fig 62 —Potometer Apparatus

(*g*) Fig 62 C shows an improvement on the ordinary potometer, consisting of a funnel connected with the potometer-tube by a piece of rubber tubing A clip is kept on the latter, the funnel filled with water, and water passed into the potometer-tube, when required, by releasing the clip

* (*h*) For experiments with small plants (*e g*. Bean seedling) or even single leaves, the apparatus sketched in Fig 61 A is convenient The rate of flow is roughly measured by the paper scale fastened to the long horizontal tube, care must be taken to make the cork and the joinings of plant and tube with it air-tight by using plasticine or wax This apparatus has, of course, the disadvantage that air-bubbles collect below the cut end of the plant and stop the water current, hence it is not so convenient to use as the potometer.

(*i*) By the aid of a simple piece of apparatus (Fig 63) and a weighing balance, the amount of water lost by a leafy stem can be determined, and at the same time it can be proved that the amount transpired is approximately the same as that absorbed by the roots A plant is fixed by means of an air-tight indiarubber cork in a bottle filled with water. As water evaporates from the leaves and is absorbed by the roots, the level of the water in the graduated tube falls. This gives the amount absorbed by the roots, and on weighing the apparatus it will be found to correspond to the total amount lost by evaporation from the leaves and stem.

Each of the larger divisions on the graduated tube corresponds to a cubic centimetre of water, so that when the roots have absorbed that amount the entire apparatus will have lost about one gramme in weight The vertical tube attached to the side of the vessel, if not graduated by engraved lines, may have a scale drawn on a narrow strip of paper and fixed to it The divisions should represent definite volumes, such as cubic centimetres. Fill the vessel with water, replace the stopper firmly, and set aside for observation The volume of water becomes less, and the amount of loss may be seen by observing the scale Enter in a book the amount of loss in equal intervals of time, and note that it is less during darkness than in the light, and also that it varies with atmospheric conditions.

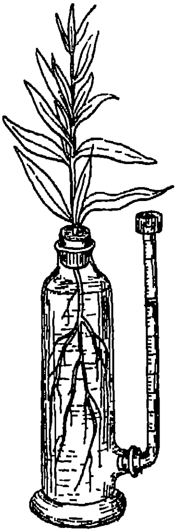

Fig 63 —Apparatus for estimating the Absorption of Water by the Roots, and the Loss by Transpiration from the Leaves.

(*j*) Fix a Wallflower or large Bean seedling in the apparatus shown in Fig 63, and determine the amount of water lost under the optimal conditions (*i.e.* in a warm, airy, well-illuminated room), either by weighing at intervals, or by watching the attached register. Then remove all the leaves and cut out twice their area in thick note-paper, to which add a piece the same length as the stem and three times its breadth. Weigh all the pieces of paper together, and also a piece a foot square. The former weight divided by the latter will give the approximate surface area of the plant in square feet. From these data the average amount of water evaporated in a given time from a square inch of surface can be calculated.

* (*k*) Another method is to use a small plant, *e.g.* a garden Geranium, growing in a tin fitted with a split cork through which passes a tube for watering. Make water-tight with plasticine, and note the loss of weight. Set beside the plant a vessel, *e.g.* a saucer containing water, and in order to compare the loss of water from the plant and from an equal area of water determine the area of the transpiring surface and that of the water in the saucer.

* (*l*) Cut three healthy leaves of Indiarubber plant or of Rhododendron, plug the cut ends with plasticine, cover the *lower* surface of one (A) with vaseline, cover the *upper* surface of the second leaf (B) with vaseline, and leave the third (C) untouched except for the plug over the cut end. Tie a piece of wire or string to each leaf, weigh each leaf carefully, then hang them up near each other and weigh them each day. After several days the leaf whose stomates are blocked (A) will be still green and fresh, while the others will be more or less withered and brown.

* (*m*) Get some **cobalt chloride** (nitrate or sulphate), make a solution (about 5 per cent.) in water, and soak some filter-papers or sheets of thin blotting-paper in the solution. Dry the papers, and observe that they turn blue. Put a drop of water on one of the dried papers, or simply breathe on it, and notice the change in colour. These cobalt-papers afford a delicate test for water-vapour. Place a thin leaf between two cobalt papers, and keep them flat by placing between two dry pieces of glass. Notice which surface of the leaf gives off most water-vapour, as shown by the change of colour.

(*n*) The cobalt-paper method enables us to tell whether the stomates are open or closed. Put two plants (*e.g.* Broad Bean seedlings) in darkness and in the morning expose one (A) to light for about an hour, keeping the other (B) in the dark. Remove and test simultaneously a leaf or a few leaves from each plant, noting the time taken for the paper in contact with their lower surfaces to turn pink; there should be a decided difference between A and B.

(*o*) Cut off a leaf (*e.g.* Tropaeolum) and let it lie on the table until it has become limp (not long enough to let it get dried up). Then cut off a fresh leaf, put the two leaves (each with lower side upwards) below a cobalt paper. Which leaf, the fresh or the wilted, reddens the paper? The experiment shows that the stomates close when the leaf withers.

(*p*) Since evaporation causes cooling (Art. 85), there must be a difference in temperature between a fresh leaf (with stomates open) and a wilted leaf (stomates closed). Wrap and tie round the bulb of a thermometer (1) a leaf cut from a Tropaeolum, (2) a leaf still attached to the plant (exposed to light), and note the readings of the two thermometers. When the cut leaf has wilted, its temperature will have risen (sometimes as much as 5°C.). Repeat the experiment, keeping the leaves in *darkness*; the temperature of the two leaves remain practically the same (why?).

(*q*) That salt-solution causes the stomates to close may be shown, without using the microscope, by means of cobalt-paper Water a Bean or other seedling in a pot with 0 5 per cent solution of common salt (1 gramme of salt in 209 c cs. of water) for a few days. Test with cobalt paper leaves from this seedling (A) and leaves from a seedling (B) watered in the ordinary way The leaves of A redden the paper much more slowly than those of B. Why is it that a *weak* salt-solution actually keeps cut or dug-up plants fresh? Plants sent by post will wilt much less if sprinkled with a weak solution of salt

245. How Leaves are Protected.—We shall see later that young leaves nearly always have some mode of protection against loss of water, they are often covered with hairs, which may disappear as the leaf grows to its full size, or they may be bathed in a gummy or resinous liquid, or they may be rolled or folded up at first. These protective arrangements are especially necessary when the leaf is young and its tissues tender and liable to lose water readily, or to be injured by strong light or by cold.

In many plants the mature leaves show similar protective arrangements, which are especially marked in plants which grow in places where they are exposed to strong light, to drying winds, cold, and other injurious conditions, such as a scanty or precarious supply of water Most evergreen plants have a thick cuticle, or a layer of clear cells below the upper epidermis, and the stomates are often sunk below the level of the epidermis. Transpiration is also diminished by the rolling up of the leaf (Heather, etc.), and by a thick covering of hairs (Woolly Mullein, etc).

It is easy to show that a dense covering of hairs checks the rate of transpiration, by using the apparatus shown in Fig 61 or Fig 62, after fastening to each leaf a piece of cotton-wool so as to cover the lower surface of the leaf, or both surfaces, and noting the effect this has on the rate at which the leaves give off water-vapour.

The effect of rolling can be observed by folding the leaf or rolling it up longitudinally to form a tube with the lower epidermis on the inside and tying it with thread, and noting the reduced rate of transpiration

Many leaves also have their surface covered with waxy matter or "bloom," so that they are not wetted by rain. This is well shown by the Broad Bean, Tropaeolum, Cabbage, Lupin, and many other plants. The "bloom" not only prevents water from entering the leaf and blocking up the air-spaces but also helps in reducing transpiration; if the "bloom" is removed from an Indiarubber Plant leaf by sponging its surface with warm water, the leaf will lose more water than one with the bloom untouched (try this experiment).

QUESTIONS ON CHAPTER VIII

1. Describe simple experiments which show through what part of the stem water ascends. How would you arrange an experiment to show the relation between the volumes of water absorbed and given off?

2. Describe some ways by which you could demonstrate that leaves give off water vapour. How do external conditions affect the magnitude of this process? What is the significance of it in the life of the plant?

3. Give an account of the process of transpiration. By what means does the plant regulate its transpiration?

4. If on a warm sunny day a plant growing in a pot had become limp and "wilted," how could you restore it to its normal condition without watering it in any way?

5. Why does the inside of a Cabbage consist of lighter-coloured, thicker, and more succulent leaves than the outside?

6. Explain why it is that plants droop on a hot day, and recover their freshness in the evening.

7. Describe experiments you have made on Transpiration, and explain how the rate of transpiration is affected under different conditions.

8. How does a plant dispose of the water which it absorbs from the soil? Describe any arrangements with which you are acquainted for regulating the quantity of water in a plant.

9. Indicate the probable presence or absence of Respiration, Transpiration, and Photosynthesis in the green and white parts, respectively, of the variegated leaf of a plant under normal conditions, (*a*) in the daytime, (*b*) at night. Give brief reasons for your answers.

10. Mention all the gases given off by a foliage leaf under different conditions. Explain briefly how you would demonstrate by experiment the evolution of these gases; and give an account of the processes leading up to their formation.

11 Explain, so far as you can, exactly how plants grown in pots in sitting-rooms are affected by draughts, by burning gas, by one-sided illumination, by the different aspects of windows, by a dry atmosphere, by injudicious watering, and by other conditions to which they are likely to be exposed

12 Describe carefully, with illustrative diagrams, two methods of finding out which side of an ordinary dorsiventral foliage-leaf gives off more water vapour To what structural features and to what biological advantage is the observed difference related ?

13 What would be the result of smearing both surfaces of all the leaves of a plant with vaseline or other greasy substance ? How would you determine experimentally the effects so brought about ?

14 What are the "veins" of a leaf ? What are their uses ? How would you show, by experiment, the correctness of your statements ?

15 If you take two similar open vessels full of water, and place a leafy shoot with its cut end in one, from which will the water disappear more rapidly ? Explain, as fully as you can, the reason for the observed result, and the nature of the processes involved

16 Explain why it is that a shoot which is cut off from a plant begins to wither and droop. How can this be prevented ? How can a flagging branch be revived ?

17 What purposes are served by the process of transpiration ? Under what conditions is this process accelerated and retarded ?

18 A green plant is in ordinary life continually giving off water Explain how this is effected, and what is its purpose How is the process affected by changes in the air and in the soil ?

19 How would you prove (1) the nature of the gas given off by a green plant in sunlight, (2) the nature of the gas given off by a green plant in the dark, (3) the nature of the liquid deposited on the inside of a bell-jar covering a growing plant ? Give an account of the processes leading to the formation of the liquid

CHAPTER IX.

THE GENERAL CHARACTERS OF FOLIAGE-LEAVES.

246. Summary of Chief Functions of the Gree Leaf.—These functions may be thus briefly summarised :—

(1) Leaves are the respiratory organs of the plant, sinc they allow a free exchange of gases with the atmosphere b means of their stomates

(2) The chlorophyll of the leaf, which, as we have provec is itself formed only under the influence of light, has th power, under this same influence, of decomposing the carbo dioxide of the atmosphere, and of building up with th carbon so obtained, together with the dissolved miner substances absorbed by the roots from the soil, the suga starch, and other organic compounds of the plant Some c the material thus formed in the leaves is transmitted to th stem and root in a soluble state, and often stored in thes organs in large quantities

(3) Water absorbed by the roots passes up the stem t the leaves, where a large proportion of it is lost by evaporatio through the stomates Water lost by evaporation in thi way is being continually replenished by the roots, and thu there is a steady upward current by means of which nev mineral matter is constantly supplied The stomates ar reduced in size by the collapse of the guard-cells whe transpiration is too active, and when the water supply i the soil is deficient They also close in darkness, when n carbon assimilation can take place; and by so doing they als prevent the plant from becoming too cold, for evaporation i always accompanied by a reduction in temperature.

The leaf primarily acts as an organ for absorbing radian energy, and storing it up as potential energy in the form o food It also promotes gaseous exchange in general, and usually forms the main transpiring surface, although transpiration, like respiration, is one of its subsidiary functions.

247. Adaptation of the Green Leaf to its Functions.—It is interesting to note how the structure of the ordinary bifacial type of foliage-leaf is adapted for its work

Its flattened form and its position are the most favourable for absorbing carbon dioxide and for catching light The epidermis and cuticle prevent excessive evaporation, besides acting as a screen against undue heating and other ill-effects of strong light Both palisade and spongy mesophyll cells, containing numerous chloroplasts, are adapted for assimilation. The palisade tissue is adapted to protect the chloroplasts from the effects of too bright light, when the light is diffused, the plastids are arranged chiefly along the upper and lower walls of the columnar palisade cells, but in strong light the protoplasm moves in such a way as to arrange chloroplasts along the side-walls of the cells with their edges (the chloroplasts are disc-shaped) presented to the light The spongy-tissue, with numerous air-spaces communicating with the atmosphere by means of the stomates, is equipped for carrying on the gaseous exchanges concerned in respiration, photosynthesis, and transpiration

The spreading veins, the larger ones projecting on the lower side of the leaf, while the smaller ones run between the palisade and spongy mesophyll, carry water (with dissolved salts) *to* the mesophyll cells and elaborated food (sugar, etc) *from* them[1] The mesophyll cells are arranged more or less definitely in groups extending from the epidermis to the veins. This is clearly seen in most leaves with well-marked palisade mesophyll, the cells of the latter being arranged in a fan-like manner as seen in vertical section (see Fig 54), and the cells which converge towards the veins have been called "collecting" or "converging" cells. The veins also serve in the best way to support the leaf; the larger veins have bands or cords of hard fibrous tissue below or above, or in both positions

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[1] The water, with dissolved salts, travels in the vessels of the wood, the dissolved sugar in the long cells of the bundle-sheath, and the proteids in the sieve-tubes of the bast.

248. Forms of Leaves.—Before quitting the study of leaves we must observe a number of their general characters—their variety of form, arrangement of veins, etc. In order to do this we shall have to examine a considerable number, and to this end the student should take country rambles, supplied with a book for notes and sketches, and a lens. The following instructions must be accepted as merely suggestive, and by no means exhaustive.

A typical leaf consists of a basal more or less sheathing portion, called the leaf-sheath or leaf-base, a stalk or petiole, and a flattened terminal portion, the blade or lamina. The leaf-sheath is usually simply the flattened basal portion of the petiole, but in most grasses it is of considerable size, and ensheathes the stem for some distance above the node from which it arises.

A sheathing **leaf-base** is frequently absent, but is especially well developed in such plants as Buttercups, Grasses, Docks, Umbellifers. The mode of insertion of different leaves exhibits a wide range of variation, but they always arise from the shoot or its branches. The so-called "radical" leaves simply arise from a very short stem (Primrose, Dandelion). In some cases the base of the leaf is *decurrent*, and forms membranous outgrowths on the main axis, while it may even unite around the stem so as to form a *perfoliate* leaf.

Occasionally the leaf-base becomes thick and fleshy, and forms an irritable organ or organ of movement known as the *pulvinus*, which reacts to light in such a manner as to place the lamina under the best possible conditions of illumination. This is possible owing to the fact that the pulvinus retains the power of growth for some time after that of the rest of the leaf has ceased, as can easily be observed by watching Kidney Beans and altering the position of the stem from time to time.

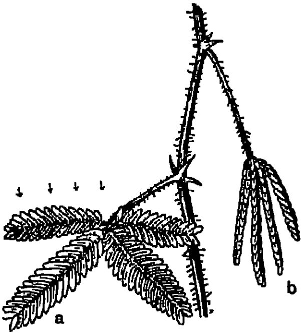

Fig. 64.—Leaves of Mimosa Pudica (the Sensitive Plant).
a, Expanded day position; b, Drooping folded night position.

In some plants the pulvinus responds quite rapidly to changes in the direction and intensity of the light. Thus the compound leaf of the Sensitive Plant (Fig. 64) places itself at right angles to the light falling upon it. Each leaflet, however, has a pulvinus of its own, and when the leaf is exposed to strong sunlight these pulvini curve in such a manner as to cause the leaflets to fold together in a few minutes, before they have time to be injuriously affected. At night, also, the leaflets fold together and go to sleep, as it were, while the whole leaf sinks downwards. In this position the leaf loses less water by evaporation, and remains warmer than it would be if expanded. The first movement is due to the action of strong light, the second to the absence of light, and their importance and utility to the plant are sufficiently obvious.

249. Stipules.—Very commonly wing-like outgrowths arise from the base of the petiole, and frequently these simply assume the form of lateral outgrowths of the leaf-base The organs in question are known as **stipules,** although they cannot always be sharply defined The stipules vary much in size, form, and colour When they are quite small, dry, pale, and membranous they are usually functionless, but frequently they form large coloured protective bud-scales (Magnolia, Fig, Beech), and fall when the leaves unfold In the False Acacia (*Robinia*) the stipules are metamorphosed into spines, and in *Smilax* they become tendrils In some Peas they are large and green, and take the place and function of the foliage-leaves, which are modified into tendrils

Stipules are often relatively large while the leaf is young, and in such cases they serve as a protection to the young buds or young foliage, frequently falling off as the leaf expands When present upon adult leaves, the stipules aid in the production of organic food if they are green, and they may also help to lead away rain-water from the plant so that it can dry rapidly, or to direct the water to those regions of the soil where the absorptive organs (root-hairs) are most abundant.

In the Rhubarb family (Polygonaceae) the two stipules join to form a tube (ochrea) enclosing the stem for a short distance above its junction with the leaf The basal portion of a Grass leaf ensheathes the stem for some distance, and just between the stem and the base of the free portion of the leaf there is a small crescentic scale on the upper surface of the latter. This scale is termed the *ligule*

250. Petiole.—Note that while some leaves have a distinct stalk (**petiole**), in others the lamina extends down to the stem of the plant. The latter are called *sessile leaves*

The petiole is usually directly prolonged into the lamina as the midrib, but in the Garden Nasturtium (*Tropaeolum*) and in the Pennywort (*Cotyledon*) the stalk is attached to the middle of the under-surface (peltate leaf) A transition stage is shown by the leaves of the Water Lily The petiole may be winged, and it is usually cylindrical or semi-cylindrical, being frequently flat or even grooved on the upper surface.

The petiole is a special secondary structure developed in order to enable the lamina to expose itself to suitable illumination, and it is not always present It contains strands of vascular tissue, which are continued into the lamina as the branching veins of the leaf There is usually a large median vein, lying above a prominent midrib, although in other cases a number of veins of equal size enter the leaf from the petiole In Garden Nasturtium (*Tropaeolum*) and Clematis the petiole has the power of coiling around supports, and hence it acts as a tendril in spite of the presence of the lamina or blade.

251. Veins.—The veins are simply conducting bundles which run outwards from the stem into each leaf, and undergo considerable branching throughout the substance of the lamina. The larger veins usually project as ridges on the under-surface, but the smaller veinlets are buried in the tissue of the leaf. The arrangement of the smaller veinlets and the number of the larger veins differ in different leaves. This is what is termed the venation of the leaf.

Note that the leaves of all grasses, orchids, flags, wild hyacinths, and daffodils have all their principal veins running parallel through the entire length, and that these leaves are more or less elongated and blade-like. The leaves of most of our trees and herbs, however, have their principal veins branching off from the midrib on either side, while the smaller ones form a delicate network such as we observed in the bean leaf. The former arrangement (*parallel venation*) is characteristic of Monocotyledons, the latter (*reticulate venation*) of Dicotyledons (but also found in some Monocotyledons, *e.g.* Arum, Black Bryony).

If leaves are allowed to decay in water until the softer parts can be brushed away, skeletons of the harder parts can be obtained which directly exhibit the venation, but in most cases it is sufficient to hold up the leaf to the light to render the smaller veins plainly visible.

252. Simple and Compound Leaves.—Some leaves are *simple*; that is, their flat part or blade (*lamina*) is not divided into distinct portions, though they may be very deeply divided. Such is the case with the leaves of the Oak, Hazel, Ivy, Dandelion, etc. These simple leaves exhibit a great variety of form, and the student should make a series of drawings illustrating the more typical shapes.

In compound leaves, of which we have already seen an example in the Bean, the blade is divided into distinct parts called leaflets, which may be arranged in opposite pairs along the central stalk as in Rose, or may all radiate from one point of the stalk as in Horse Chestnut.

The outline of the lamina assumes a great variety of forms, and special technical terms are given to the more strongly marked and more commonly occurring of these. All gradations exist between leaves of widely different shape, and since no general principles are involved in the application of these terms, they need not be discussed here. The following list includes the commonest shapes:—

(1) **Blade broadest near the base**—*e.g.* **cordate** (heart-shaped), **sagittate** (arrow-head-shaped), **reniform** (kidney-shaped), **ovate** (egg-shaped), **lanceolate** (lance-head-shaped, much longer than broad, tapering to pointed tip).

(2) **Blade broadest near the tip**—*e.g.* **obcordate, obovate, oblanceolate** (outline as in cordate, ovate, and lanceolate, but with the narrow end at the base), **spathulate** (spoon-shaped, *e.g.* Daisy).

(3) **Blade as broad in the middle as anywhere else**—*e.g.* long narrow forms, as **acicular** (needle-shaped), **linear** (long and narrow, with parallel margins), **cylindrical**; and rounded forms, as **orbicular** (circular), **elliptical, oval, peltate** (shield-like, blade nearly circular, but with stalk near the middle of lower surface).

Next observe the different kinds of **margins** of the blades. Some are even or *entire*, while others have sharp teeth which usually point towards the tip of the blade and resemble the teeth of a saw (*serrate* leaves), or have rounded teeth (*crenate* leaves). Note also the hairy (*ciliate*) margin of the Beech leaf, the wavy or *sinuate* margin of the Oak, the irregularly toothed edge of the Dandelion, the spiny margin of the Holly, and various other modifications of leaf margins, all of which should be drawn from nature.

Very frequently the margin of the leaf is deeply indented, and if the indentations are regularly arranged, and are so deep as to reach the midrib, a compound leaf composed of a series of leaflets is produced. This will be *pinnate* or *palmate*, according to the arrangement of the main veins (Fig. 65), for the incisions will naturally fall between these.

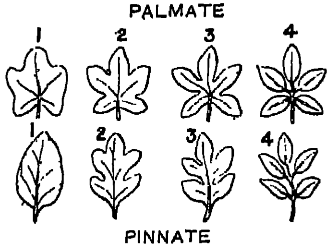

Fig 65.—Formation of Palmate and Pinnate Compound Leaves by the gradually increasing incision of Laminas with Palmate and Pinnate Venation respectively.

Compare the simple leaves of the Ivy and the Beech, both of which are of the net-veined type. Note that in the former the principal veins all radiate from one point at the base, while in the latter they branch off from the midrib almost throughout its length. Now since a compound leaf is produced by the division of the lamina between the principal veins, it is easy to see that the former, so divided, would produce a compound leaf with radiating leaflets. Such an arrangement of veins is termed *palmate venation*, and the leaves, both simple and compound, more or less divided in this fashion, are called *palmate leaves*. The arrangement of veins in the second instance is called *pinnate venation*, and by the incision of the lamina a *pinnate leaf* is produced, which, in the case of the compound leaf, would have opposite leaflets.

A compound leaf is easily distinguished, even by beginners, from a branch bearing leaves because of the absence of any apical bud or growing point, and by the fact that a bud occurs in the axil of the main petiole, whereas there are no buds in the axils of the leaflets.

253. Leaf-Arrangement.—Observations should also be made of the different ways in which the leaves are arranged on the stem. There are two ways in which leaves are arranged—*alternate* (one leaf arising at each "node," *i.e.* the leaves coming off *singly* from the stem) and *whorled* (two leaves, rarely more, arising at each node).

The simplest type of alternate arrangement is that seen in the Broad Bean and in Grasses, where the leaves come off alternately from opposite sides of the stem, so as to form two rows; this is called the $\frac{1}{2}$ arrangement, because each leaf is separated from the next above and below it by one-half the circumference of the stem. The next arrangement ($\frac{1}{3}$) is seen in young shoots of Hazel, where the leaves are in *three* rows. Alternate leaves obviously form a *spiral*, the nature of which may be easily determined by tying a piece of cotton to the base of a leaf, and carrying it in order to the bases of the leaves above, twisting it around each one. Suppose, for instance, we do this in the case of a young shoot of the Hazel, we find that each leaf is one-third round the stem as compared with the one below it, and consequently the fourth leaf is vertically above the first, being the starting-leaf of a second turn of the spiral.

One of the commonest spiral or alternate arrangements is the $\frac{2}{5}$, seen in Wallflower, Oak, and many other plants; here the sixth leaf is above the first and the spiral goes twice round the stem in passing from the first leaf to the sixth. Another fairly common spiral is the $\frac{3}{8}$, seen in Daisy, Plantains, etc. Do you notice how these commoner spiral arrangements are related to each other?

When leaves are arranged in pairs, the two leaves being on opposite sides of the "node," each pair is usually set at right angles to the pair above and the pair below. That is, the leaves are in four rows, the pairs being crossed. This *decussate* arrangement is very common, *e.g.* Nettles, Labiates, Sunflower, Sycamore, Ash, Lilac, Horse Chestnut, Campions, Stitchworts, Chickweeds. Comparatively few plants have three or more leaves in a whorl or circle at each "node", this is seen in Mare's-tail (*Hippuris*) and in Heaths. The leaves are *apparently* in whorls in Goosegrass and Bedstraws, but only two of the organs in each circle are true leaves (how can you tell this?).

254. Leaf-Mosaics.—Instead of giving further details here about the various modes of arrangement of leaves on the stem, we will call attention to the *reasons* why leaves have such varied arrangements and shapes. It is not always easy to explain the different forms of leaves in different plants, but some general principles can be inferred by remembering the *functions* carried on by leaves while studying their form and structure. The main fact to remember is that leaves require to catch as much sunlight as possible, especially in a country like ours, where the number of hours of sunshine is rather scanty. The south coast of England only gets about 1,600 hours of sunshine annually, and in the rest of Britain the number is usually far below this.

A leaf which receives very little light or no light at all during its development grows feebly, and cannot, of course, carry on carbon-assimilation. Moreover, when a leaf is shaded by another leaf being placed between it and the light, very little assimilation occurs. Hence we find that in many plants the leaves tend to fit together like the bits of glass in a mosaic or the tiles in a pavement, so as to avoid shading each other and to lose as little sunlight as possible This tendency is easily seen in (1) plants whose leaves are crowded together and form a rosette close to the ground—*e g* Daisy, Hawkweed, Plantain, London Pride, (2) many plants with whorled leaves—*e.g* Woodruff; (3) twigs of many trees—*e g* Horse Chestnut, Beech, Elm, Lime, (4) twigs of plants which creep along a wall or bank—*e g* Ivy. In Labiates (*e g.* Dead-Nettle) and Stinging-Nettles the lower leaves have broader blades and longer stalks than the upper ones

Even when the "mosaic" tendency is not at first glance apparent, careful study of the plant *in its habitat*, or home, will often show adaptations for efficient light-catching It must, of course, be remembered that the strongest light does not, in this country, come from directly above, but at an angle, even when plants are growing on level ground. In studying the plants dealt with in the later chapters of this book, you should notice and try to account for the position, stalk-length, shape of blade, and other arrangements of the leaves, remembering that, besides the tendency to catch as much light as possible, the forms of leaves are often influenced by other causes—*e g* the necessity to withstand high winds, to carry away rain which falls on the blade, to catch the light when growing in dense masses (*e g* grasses and plants growing among them in fields).

This interesting subject can only be studied by personal observation, any field, wood, hedgerow, or garden will afford abundant material to illustrate the points here mentioned, and to show how the arrangement and shapes of leaves help plants in the struggle for light and air, which is keenest where plants are growing in crowded fields or hedge-rows.

255. Decay and Fall of the Leaf.—Leaves which fall before the vegetative season is over are *caducous*, *deciduous*, if they fall at the end of each season, as in most cases of our forest trees, *persistent*, if they remain on the plant for more than one season, as in evergreens The leaves of such plants as Grasses, Lilies, Irises, etc, simply wither on the stem, but in most trees the fall of the leaf at the end of the vegetative season is brought about by the plant itself. When the activity of such leaves is nearly over, and they have been partly emptied of the food-substances they contain, a layer of cork-tissue forms across the base of the leaf, and by interposing an impermeable layer between leaf and stem, cuts off from the former all supplies of water and mineral salts

The exact structure and development of this **absciss-layer** cannot be fully gone into here, but what occurs in the actual "fall" of the leaf is the splitting of this layer in such a way that the leaf only hangs on by the veins which pass from it into the stem, and then these snap, leaving the scar of attachment of the leaf already healed and covered with cork. The process is a vital one due to the activity of the living plant, for if a branch is killed by means of hot water the leaves wither upon it without being shed. On the other hand, leaves can be made to "fall" in summer by wrapping them in a damp cloth

Whenever the plant requires to throw off certain organs at a definite time (petals and other floral parts after fertilisation; fruits and seeds when ripened) it generally makes use of similar absciss-layers.

QUESTIONS ON CHAPTER IX.

1 What do you consider the essential characters of the foliage-leaves of a green plant, i e the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

2. Mention the different forms which may be assumed by the stipules of plants Give one example of such, and state the special use of the stipules in each case.

3 How are the leaves arrayed on the twigs of a Horse Chestnut (or a Sycamore)? Point out any special adaptations which bring about the full exposure of the leaves to the light.

4 How would you distinguish a compound leaf (*a*) from a simple leaf, (*b*) from a branch bearing leaves?

5. Mention some leaves which show movements Of what use are the movements to the plant?

CHAPTER X.

ROOTS AND THEIR WORK

256. The Work of the Root.—We have seen that ordinary roots have two main functions—fixation and absorption Since they have no chlorophyll, they cannot make organic food for themselves, and must therefore be supplied with such food by the assimilating organs

We have studied in some detail the current of water, with dissolved salts, which passes upwards from roots to leaves How is this transpiration current set up and maintained? What part does the root play in the process? These questions are by no means so easy to answer as one might suppose

257. Root-Pressure.—In the first place the evaporation from the leaves tends to suck fresh supplies upwards to replace that removed by the air in the form of water-vapour, and in the second place the roots and stem seem to exercise a pushing force (**root-pressure**), driving water upwards Experiments with leaves or shoots cut off and set in water prove that the leaves *draw* water upwards How can we find out whether water is *forced* upwards by the root?

* (*a*) Choose a healthy Bean seedling growing in soil in a pot, and cut across its stem about 3 ins above the soil Tie a bit of stout rubber tubing, a few inches long, on the stump, and fill this tube with water, then tie into the rubber tube a glass tube of fine bore (capillary tubing) Support the glass tube horizontally by means of a cleft stick, squeeze the rubber tube so as to force some water out of the end of the glass tube and absorb it with blotting-paper, then release the rubber tube so that air is drawn into the glass tube Watch the advance of the water (which should be coloured with red ink) along the glass tube Try this experiment with vigorous plants of various kinds growing in pots.

(*b*) Cut off the stem close to the ground, and connect the stump t long, straight piece of glass tubing, lash this tube to a stick placed the soil, pour a little water into it, then a drop of oil, which will flo on the water and prevent evaporation Measure the ascent of t water in the tube, and find out how the rate is affected by temperatu

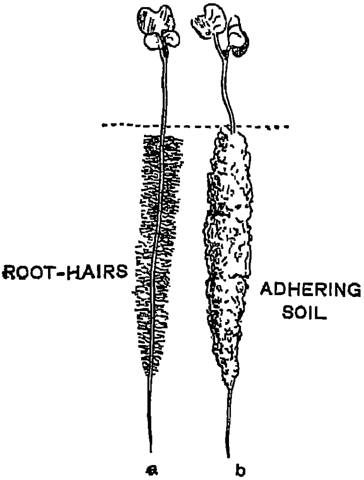

Fig 66 —Mustard Seedlings grown in Sand (*a* has been gently shaken in water).

258. Root-Hairs are developed on roots a short distan behind the root-cap The soon die away from th older parts of the roo They come into very clos contact with the earth particles, so that whe the root of a seedling lifted from the soil a por tion of the latter adhere wherever root-hairs ar present (Fig 66), but no where they are absent.

The surface of the roo is increased at least fift or sixty times by the root hairs The root-hai come into contact wit the water around the soil particles, and each hai becomes surrounded by film of water. Some root contain sugar (Carrot Beet, Parsnip, etc.), an by chemical tests we always find in roots sugar or other sub stances that are capable of "attracting" water. We hav here the conditions under which *osmosis* occurs—two solution separated by a permeable membrane (cell-wall of root-hair), and we may infer that soluble substances in the soil-water diffuse into the root-hair, while some of the substances dissolved in the cell-sap of the root-hair diffuse into the soil.

* (*a*) Root-hairs are especially well seen on the roots of seedlings (Figs. 31, 43, and 66) In seedlings of Wheat, Radish, Turnip, Cress, or Mustard, grown on muslin stretched over a tumbler of water, the hairs are very abundant. An even better method is to place the seeds in an earthenware dish, or on pieces of brick or broken plant-pots, and keep

them moist, covering them with a sheet of glass or a bell-jar, the root-hairs are freely developed in the damp air, forming a white fleecy covering on the roots

* (b) Make a rough model of a root-hair out of a long potato-tuber Cut off one end of the tuber so that it will stand upright, and with a knife scoop out the middle part, leaving on the outside a layer about a quarter of an inch thick Half-fill the tuber with salt solution or sugar solution (about 5 per cent in each case), coloured with red ink, and stand it in a dish of water, the level of which should not exceed that of the salt or sugar solution inside the tuber From day to day observe the rise of the coloured solution, showing that water has been absorbed from outside.

259. How is Root-Pressure set up?—The process of osmosis through the thin cell-wall of a root-hair is largely influenced by the layer of living substance (protoplasm) within the cell-wall, which allows only weak solutions to pass into the hair, and which retains the water in the cell-sap at a high pressure The tense condition of the root-hair thus set up is called turgidity It is really osmotic pressure, regulated by the influence of the living protoplasm layer If the "artificial root-hair" is placed in a solution stronger than that which is inside it, water is drawn out Exactly the same occurs with the real root hair Its stiffness or turgidity is, like the stiffness of an inflated bicycle-tyre, due to the pressure inside it This pressure in the root-hair is due to absorption of water—hence, when we draw this water out the root-hair collapses or becomes flaccid The presence of salts in large amounts in soil-water hinders absorption by the root, this is exactly what the root has to endure in salt-marshes and peat-bogs

When the pressure thus set up in the root-hair reaches a certain point the protoplasm of the root-hair undergoes a change, so that it allows the cell-sap to be forced into the cells of the cortex at the base of the root-hair. Each cell in turn, as we pass inwards in the cortex, repeats this process, alternately becoming turgid and collapsing, so that the water with dissolved salts eventually reaches the central cylinder, and is forced into the wood-vessels.

The effect of the millions of root-hairs absorbing water and passing it on to the cortex-cells, which pump it into the vessels, is to produce considerable pressure, which we may regard as a force driving the water into the wood-vessels and upwards In some plants it is very marked, especially in spring, but it can be demonstrated in most plants while active growth is going on and there is sufficient water in the soil Many plants "bleed" when cut; this is often seen in trimming or pruning plants, especially in spring or early summer

260. Available Plant-Food in Soil.—We have seen that root-hairs can only absorb dissolved substances. Salts insoluble in pure water and required by plants are brought into solution in various ways, chiefly by the carbon dioxide present in soil-water and by the changes due to the various chemical processes we have just mentioned. It is easy to prove tha root-hairs give out acid sap, and that they give out carbo dioxide, which accounts partly, at any rate, for the aci reaction they give with litmus. In these different ways th elements essential for plant-food are made available for th use of plants.

A complete chemical analysis of a soil, though giving th limits of the plant-food the soil can supply, often gives littl practical information as to its fertility or its need for manure. It is necessary to know, as far as possible, the amounts o the essential elements which are directly available for the us of plants. One method, used to determine the amount o available phosphoric acid, for example, is to treat the soi with a 1 per cent. solution of citric acid, which represent the average acidity of the sap of roots and root-hairs.

(*a*) Grow seedlings with their roots resting on wetted blue litmu paper, or dipping into blue litmus solution, and notice the change o colour, due to the acid substances excreted by the root-hairs.

(*b*) Grow seedlings in a layer of sawdust or soil resting on a slab o polished limestone. After a week or so, when the roots have reache the slab, remove the latter and examine the surface closely for th tracks eaten into it by the roots.

(*c*) To show that roots give out carbon dioxide, it is only necessar to grow seedlings for a short time with their roots dipping into lime water; set up a control experiment, with a jar containing lime-wate but no plant.

261. Fertility of Soil.—From what has been already said, it is easy to understand that the fertility of a soi depends on the existence of suitable relations between its (1) mechanical, (2) chemical, and (3) biological properties.

(1) No matter how rich a soil may be in plant-food, it cannot reach a high degree of fertility unless it has the proper fineness of texture, porosity, water-holding power, and other physical properties which are essential to allow the roots of plants to grow readily in it and be supplied with sufficient air and water.

(2) It is also essential that the soil contains a suitable store of plant-food in an available condition. However suitable the structure of the soil, it cannot give the best results if the plant-food (or any essential part of it) is present in insufficient amount or in an insoluble or unavailable form.

(3) Since the conversion of one of the most important elements in plant-food, nitrogen, from combination in complex and insoluble organic substances into the directly available nitrates is the work of certain Bacteria, it is obvious that these micro-organisms must be present in the soil in order to make it highly fertile

262. How Soil is Improved.—There are various methods of improving the soil and making it fertile or keeping it so The physical condition of soil is improved by tillage operations (*e g* ploughing, harrowing, rolling, draining), also by adding to the soil materials which alter its mechanical properties (*e g* lime or bulky vegetable refuse) Improvements in the chemical condition of soil are made by (1) adding substances which contain plant-food, (2) adding substances which act upon insoluble compounds present in the soil and make available the plant-food they contain The chief methods of improving soil, then, are *tillage* and *manuring*

263. Tilth.—The physical condition of a soil is called its *tilth.* A soil consists of grains of various sizes, and it is in good tilth when the grains are neither too fine nor too coarse, and when they are not too firmly cemented together Since the soil-grains are more or less rounded, when they are massed together without being crushed a large amount of space exists between them, this space is required for movements of air and of water If the grains are too large and too loosely packed, the soil lets rain fall through it too freely, and does not bring it back rapidly enough, by capillarity, to meet the needs of plants If the grains are too small and too closely packed, the water moves too slowly, too much is retained by capillarity, and there is too little air If the grains are bound together too strongly, the soil is too hard, and roots cannot grow freely in it A soil is in good tilth when the soil-grains are of the proper size and there is a good circulation of air

264 Tillage.—This term is applied to the different methods of working or tilling soil in order to secure the conditions necessary for the growth of cultivated plants The chief objects of tillage are to destroy weeds, to place below the surface manure and other organic matter, where it may be rapidly converted into humus, and to modify the condition of the soil in regard to openness of texture, temperature, movements of soil-water and of soil-air The early tillage of the soil before sowing in spring has for its main objects the changing of the soil-texture so as to make the soil warmer, drier, and better aerated, also to diminish the rate of evaporation of the deeper soil-water, and to hasten the germination of weed-seeds so that the weeds may be destroyed before it becomes difficult to get them out owing to the presence of the crop itself

Good tillage is essential, because it (1) improves the physical condition of the land, which is even more important than its richness, for no matter how rich a soil may be, plants will not thrive in it while it is cloddy, lumpy, and ill-tilled, (2) saves moisture by deepening the friable bed, so increasing the water-holding capacity of the soil, and by making, and renewing as often as it becomes crusted over, a surface mulch of two or three inches of loose earth, which serves to break the capillarity tubes and so to prevent excessive evaporation of moisture from the land, and (3) increases the supply of available plant foods in several ways The more thoroughly pulverised the soil, the greater is the quantity of water it can hold.

The great body of water in the soil is acted on by the force of gravity, and seldom rises within 18 inches of the surface of cultivated lands From this "gravity-water" moisture rises to the surface by capillary attraction whenever the surface soil is drier than that beneath Now, as water rises more easily to the surface when the soil is well tilled than when in a cloddy condition, it would at first sight appear that deep cultivation results in a loss of soil-moisture, but deep tillage is absolutely necessary to provide the reservoir for water, and experience proves that a well-maintained soil-mulch largely checks evaporation from land by breaking the capillarity tubes and so interrupting the upward flow of water

This soil-mulch is prepared by specially tilling the top two or three inches of soil, and it constitutes the most efficient agent for preventing waste of water by evaporation It is, of course, important to renew the soil-mulch from time to time Not only does cultivation of these top two or three inches actually break the capillarity tubes, but it covers the under-soil with a layer of soil-particles too loose for water to rise freely through it. Rolled and caked lands give off an immense amount of water by evaporation, because the capillary tubes are in full working order under such conditions, so that it is important to renew the mulch after rolling and when the surface has been caked by rain The harrow chosen to prepare the surface-mulch must be one which stirs the whole surface of the ground, and leaves it tolerably smooth afterwards

265. Manures and Fertilisers.—Various materials are applied to the soil in order to replace certain elements which in time become deficient owing to the growth of plants and to loss by drainage The chief elements which it is necessary to replace in this way, in order to keep the soil fertile, are **nitrogen, phosphorus,** and **potash. Lime** is also used largely, but more on account of its action on other soil-substances than as direct plant-food Manures are usually valued according to their richness in nitrogen, phosphorus, and potash. "Chemical" manures or fertilisers are used to supply one or other of these elements, while the more complex "natural" manures contain varying quantities of all the essential elements

As a rule, low-lying, moist, and rich soils are likely only to be deficient in phosphates, while potash and nitrates are the chief substances lacking in lighter, higher situated, and more exposed lands.

(*a*) If a garden or field is available for experiments with fertilisers, arrange a set of beds, each bed a yard square, separated from each other by at least a yard (to prevent the fertiliser from diffusing), and in each bed place a different fertiliser, working it into the soil with a spade. Find out from farmers or seedsmen the amount of each fertiliser used per acre and divide to find the quantity required for a square yard (an acre = 4840 sq yds) In each bed sow Wheat or other crops (change them each year), and keep the watering and other conditions as nearly alike as possible in all the beds Leave one bed without fertiliser , on the others place one of the following (1) farmyard manure (well rotted), about 1 lb , (2) Chili saltpetre (nitrate of soda), 1 oz ; (3) superphosphate, 1 oz ; (4) kainite, or carbonate of potash, 1 oz , (5) quicklime, 1 lb

(*b*) Another method is to place the soil, well mixed with one or other of these fertilisers, in pots, using quantities corresponding to the area of the soil-surface. Use a series of pots for each fertiliser, placing different quantities in each pot, and grow the same kind of plant—*e g* Wheat—in each set of experiments The other conditions—*e g* watering, exposure to light—should be kept as nearly uniform as possible in all cases

266. Selective Absorption by Roots.—It is well known to farmers that on most soils it is better to change the kind of crop grown from year to year, instead of growing the same crop year after year. This is because different plants have different needs, and take their food elements in different proportions from the soil For instance, cereals (Wheat, Rye, Barley, Oats) take from the soil less than half as much nitrogen, lime, and potash as "root-crops" (Turnip, Mangold, Beet, Potato) Hence crops with similar needs are raised alternately, instead of in succession, on the same field, this alternation is called the "rotation of crops" When a plant is grown in a solution containing sodium nitrate (Chili saltpetre), it takes up all the nitrogen and only a trace of the sodium, because far more nitrogen is used by the plant than sodium

267. Roots as Storehouses of Food.—In annual plants the food produced by the plant during the growing season is mostly turned at once into new tissues The only store of reserve food is that laid by in the seed for the use of the young plant when germination occurs. In biennial plants (which in the first year produce leaves and make and store up food, and in the second produce flowers and fruits) reserve food is often stored in the roots, which are greatly thickened, as in Carrot, Beet, etc In these cases the so-called tap-root really includes part of the stem in addition to root proper, and in Turnip and Radish the whole of the swollen part corresponds to the hypocotyl of the seedling

In perennial plants the roots may be annual, as in Lilies and other plants with bulbs or rhizomes, or biennial, as in Dahlias, or perennial, as in shrubs and trees Roots that are annual—*i e.* perishing the same year in which they are formed—contain no reserve food, but roots that last two or more years nearly always contain more or less food for the following year's growth

Adventitious roots may be used for the storage of food, as in the tuberous roots found in many Orchids (Fig 68) The tubers may be either palmate or globular, and they arise adventitiously from buds which appear at the base of the present year's stem Next year a new stem develops from this bud at the expense of the nutriment stored up in the tuber In the case of the Dahlia and Paeony, adventitious tuberous roots grow out from the base of the stem (Fig 67), and these are put to a similar use as storage houses for reserve-materials That these bodies are really roots is shown by their development as irregular endogenous outgrowths at the base of the stem, which do not arise in the axils of leaves and are at first covered by a root-cap

(*a*) In Radish seedlings, make sketches of young plants of different ages, showing the cotyledons and the red hypocotyl, the thickening of the hypocotyl, and the fully formed swelling Cut thin cross-sections of the "root" (hypocotyl) of a young seedling, and notice the very marked circular transparent zone of growing tissue (*cambium*); test with iodine and notice the starch present in most of the cells except those of the cambium The cambium consists of narrow oblong cells, arranged in the radial rows, filled with protoplasm, and continually dividing to form new cells on the outer side (bast) and on the inner side (wood) of the cambium-layer, the wood contains but few vessels.

(*b*) Study and compare the roots of Carrot, Parsnip, Beet The Beet root is peculiar in having several layers of cambium instead of one only Scrape the root of Carrot and that of Parsnip, put the scrapings in warm water, shake up, and filter Test the filtrate for sugar with Fehling's solution The reserve food in the Beet is also sugar, but it is cane-sugar, not glucose, as in Carrot, etc Hence, in order to get the red precipitate with Fehling's solution, it is necessary to boil first with sulphuric acid in order to convert the cane-sugar to glucose (*c*) Examine the tuberous roots of Dahlia, which are formed in summer and store up food to be used by the flowering stems of the next year (Fig. 67). When exhausted of food they die off, but new tubers are formed as the old ones are emptied, so that the individual plants can carry on a perennial existence. The reserve food in this case is inulin, similar in composition to starch, but differing in being soluble in water, so that in a section of fresh root examined in water the cells appear empty. If a piece, or a section, of Dahlia tuber be placed in alcohol for some time, the inulin is deposited in the cells as rounded crystal-like masses.

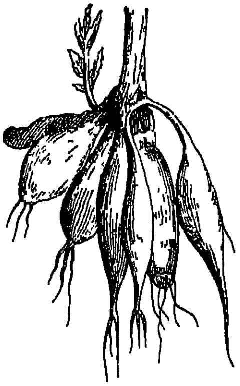

Fig. 67.—Tuberous Roots of the Dahlia.

(*d*) Dig up an Early Purple Orchid and trace the shoot down, below the inflorescence and the leaves, to the basal swelling, which is a root-tuber. Cut the tuber across and test the cut surface for starch. Besides the tuber in which the present year's shoot ends, notice the brown and shrunken tuber formed last year, and the new tuber being formed for next year. To see these tubers of different ages and to trace their life-history you must of course examine plants at different times of year.

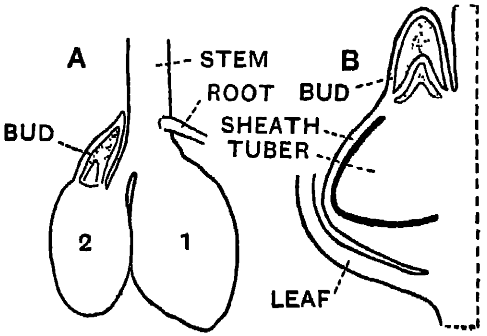

Fig. 68.—Orchis. A, Base of a Plant (dug up in summer), with old (1) and new (2) Tubers; B, Section of a developing Tuber.

Each year one root (sometimes two), instead of growing out like the other roots, becomes swollen up and packed with food (made by the green leaves and transported downwards through the stem); this root is formed at the base of a bud, from which next year's leaf- and flower-bearing shoot will develope (Fig 68) When the shoot dies, the root-tuber, with the bud above it, remains in the soil during winter, and the early growth of the shoot takes place at the expense of the food stored in the tuber, while ordinary roots grow out to absorb water and salts from the soil

QUESTIONS ON CHAPTER X

1. Trace the path followed by a particle of water, from its entrance into the root to its exit, as vapour, from the leaf

2 On what part of the root are root-hairs found? Under what conditions are the most conspicuous root-hairs produced? What is the function of root-hairs? How can you imitate the process involved by a mechanical contrivance?

3 Show how some of the commoner operations of gardening, such as digging, manuring, raking, transplanting and watering, may be conducted, so as best to minister to the chemical and physical conditions of plant life

4 How would you examine a handful of soil to see if it contained any soluble salts?

5 How could you prove that nitrates (of soda, potash, or lime) are present in a fertile soil?

6 Describe carefully and illustrate by diagrams the details of the procedure you would follow in order to find out the differences produced in the roots of seedlings by growing (*a*) in ordinary soil, (*b*) in water-culture solution, (*c*) in damp air. What differences would you observe between the roots in the three cases, and how are they related to the different conditions of life? What would be the ultimate fate of the three sets of seedlings?

7 Explain why it is injurious to plants grown in pots to be too frequently and too abundantly watered

8 Can you measure the moisture present (*a*) in the soil, (*b*) in the air? State exactly what effect each has on a growing plant, and how you would demonstrate the effect in each case

9 What are root-hairs? Where do they occur, and what is their function?

10 Why should a farmer keep his crops free from weeds? In what way are weeds harmful if this is not done?

11 How do root-hairs help the root to absorb the water of the soil as thoroughly as possible? Under what conditions will root-hairs be (*a*) abundantly, (*b*) scantily developed?

12 What is root-pressure? How is it set up, and how can it be demonstrated and roughly measured?

13 Describe the chief agencies by which soil is formed What are the differences between "sedentary" soils and "transported" soils?

14 What are the chief constituents of ordinary soil, and how may they be separated?

15 Describe the characters of sand, clay, limestone (chalk), and humus, with reference to the growth of plants

16 How do the chief soil-constituents differ as to capillarity, ability to retain water, and usefulness as sources of plant-food?

17 What substances are found dissolved in soil-water? Describe the three conditions in which soil-water exists? Why is excess of free soil-water injurious?

18 How does soil-air usually differ from that in the atmosphere?

19. What is meant by "available plant-food" in the soil? Explain why some soils may be rich in the essential elements of plant-food and yet be poor soils in which to grow plants.

20 How are plants enabled to make use of substances in the soil which are not soluble in water? What part do root-hairs play in the process?

21 What is meant by a "fertile" soil? Upon what conditions does the fertility of a soil depend?

22 In what ways can a soil be improved, both as regards its texture and its richness in plant-food?

23. What is "tilth"? What tools are used in tillage, and what is the mode of action of each?

24 Why is it necessary to use manures and fertilisers on cultivated soils? Mention the chief fertilisers used, and the reason for using each of them.

25 What is meant by "selective root-absorption," and how is it related to "rotation of crops"?

26 What special function is performed by the roots of most biennial plants and some perennials with regard to food-storage?

27 What is a soil? What is meant by "light" and "heavy" soils? What are their respective advantages and disadvantages for the growth of plants? Give any instances you know of rocks or strata which produce light and heavy soils respectively

CHAPTER XI.

THE GROWTH OF ROOTS AND STEMS

268. As we have seen, the green leaf makes organic food from the raw materials which it takes from the air and from the soil It also serves as the chief means by which the air within the plant communicates with the atmosphere, and by which the gaseous exchanges concerned in respiration and transpiration are carried on These functions are also carried on by the other green parts of plants, *e g* by young stems, both in herbaceous and woody plants, since the rind (cortex) contains chloroplasts, and the stomates (on herbaceous stems and the youngest parts of woody stems) or lenticels (in older parts of woody stems) communicate between the air-spaces in the plant and the atmosphere outside

We have already learned something about the growth of roots and shoots from our work on seedlings and on the nutrition of the green plant We may now take up the questions on the growth of root and shoot raised in Art 189 It is absolutely necessary to grasp thoroughly the main facts in the nutrition of plants—above all, the **work of the green leaf,** which is the great fundamental process and which may be said to form the key to the right understanding of the structure and development of root and shoot and all the varied forms and adaptations of the vegetative organs

* **269. How to measure the Growth in Length of Root and Stem.**—Seedlings of Broad Bean, Garden Pea, and Scarlet Runner are suitable for experiments on the growth in length of root and stem. Place the seeds in damp sawdust with the scar downwards. Runner Beans are especially useful for measurements of the growth of the stem.

When the root has grown about 2 inches long, dry i surface carefully, stroking it with torn bits of blotting-pape and with a fine brush mark it at intervals of $\frac{1}{8}$ inch, startin at the tip, with dots or transverse lines of Indian ink

The stem of a French or Runner Bean seedling should l marked in the same way, starting at the point where the fir pair of foliage-leaves stand on the stem and working dow wards, seedlings of Sunflower or Mustard may be used, th hypocotyl being marked starting from the cotyledons

* **270. Where does Growth in Length occur?**—Pin seedling with marked root to the cork of a glass jar, exactl as in Fig 33 Examine from time to time and note th positions of the marks, after a few days, the marks jus behind the tip of the root will be widely separated, whil those farther back have changed little, or not at all, in position What conclusion can you draw from the results o experiments like this? To what region of the root is growt in length almost entirely restricted?

A neat method of arranging this experiment is to put th seedling into a thistle-funnel and let the root grow down th tube, the latter is set in a jar of water, while the seed i covered with some wet blotting-paper or cotton-wool. Thi plan, allowing the roots to grow very long, gives striking proof of the fact that growth in length chiefly occurs just behind the root-tip An ordinary glass funnel may be used instead of a thistle-funnel.

Daily observations and measurements of the hypocotyl of a French Bean seedling, or the young shoot of a Runner seedling, will show that in the stem, as in the root, growth in length is much more vigorous just behind the tip than farther back

271. How the Young Root enters the Soil.—You have seen that the root end of the axis is the first part of the young plant to emerge from the seed, and that on emerging it grows downwards, in whatever position the seed has been placed Have you tried the effect of moving the seed at this stage, and then turning it over each time the root has curved so as to be directed downwards? Have you noticed how, if a seed is laid on firm soil, root-hairs grow out and fix the root to the soil, giving it a "purchase," so that it can push its tip down with greater force? Have you noticed how the lighter kinds of seeds are often raised up or turned over by the struggles of the root to bore into the soil? How can the downward pushing power of the root be measured, say in a Broad Bean seedling?

* (*a*) You have probably used mercury in various experiments, and know that it is a very heavy liquid (13½ times heavier than water). Fix a seedling (Bean, Pea, etc., should be tried) to the side of a small dish containing mercury with a layer of water above it, and see whether the root will grow down into the mercury. The seeds may be pinned to a cork which is securely fixed to the rim of the dish (*e.g.* a saucer) by making a slit in it and jamming it tightly on the rim; each seed should of course be fixed by *two* pins.

(*b*) One method of roughly measuring the pushing power of the root is to make it press a cork, or a chain of corks, downwards into water. Cut a slit in a cork so that it can be firmly fixed to the rim of a tall, narrow jar or a large test-tube, and to this cork pin a Bean seedling (with a root about 2 ins. long) so that its root projects into the mouth of the tube. Then place in the tube a number of corks, one above another, of such size that they can move freely inside the tube; the row of corks should be about half as long as the tube. In the uppermost cork make a cavity for the root to press downwards against, and pour some water into the tube so that the root fits into this cavity. Place a vertical strip of paper on the tube, on which to mark the position of the lowest cork from day to day, and put some wet cotton-wool or blotting-paper over the seedling to keep it moist.

Each day pour a little more water into the tube (which should be fixed in the vertical position), and thus increase the resistance against which the root has to push downwards. When the root seems unable to push the chain of corks any farther down, mark the position of the bottom of the lowest cork, then take the seedling out and find what weight (*e.g.* of shot in a test-tube) is required to depress the corks to the mark. By finding the diameter, and from this the area, of the root just above the tip, you can calculate the pressure of the down-growing root in grammes or ounces per square centimetre or square inch.

(*c*) Fix a young Bean-seedling so that its root grows in a small tube filled with moist soil or sawdust, and place this tube within a larger one containing a spring. The root grows downwards with a force equal to over 300 grammes (about 11 oz.); measure the diameter of the root and calculate the force it exerts per square centimetre or square inch.

272. What makes the Main Root grow downwards and the Main Stem upwards?—Most likely this question would not have occurred to you at all, or if it had you would probably have thought of anything but the right answer or the right way to test the matter It is clear that the root *does not simply bend down by its own weight*, like a rod of plastic material, for it exerts great force in its downward growth Besides, this "explanation" would not apply to the shoot, nor even to the side-roots, the former grows upwards, the latter grow away from the parent-root

If the young root is placed horizontally, it soon begins to bend downwards, the curvature taking place just behind the growing apex This curvature is soon rendered permanent by the growth and hardening of the tissues affected, but a new terminal straight portion of the root is soon formed as growth continues, and if this be again laid horizontally a downward curvature is produced as before This curvature is due to the fact that **gravity**, the attractive force which the earth exerts on all bodies, acts as a stimulus upon the protoplasm at the apex of the root, and causes the growing region to bend towards the centre of the earth

The growth-curvatures by which root and shoot respond to the stimuli of gravity, light, moisture, etc, are called **tropic** movements (Greek *tropos*, direction) In most plants, the root is positively geotropic, negatively heliotropic, and positively hydrotropic, while the shoot is negatively geotropic (response to gravity), positively heliotropic (response to light), and negatively hydrotropic (response to moisture)

* (*a*) That it is not the action of the *soil* which causes the root to grow downwards is readily shown, *e g* by growing seedlings in moist air Choose a few Bean seedlings with straight roots about $1\frac{1}{2}$ ins long Dry the roots gently by stroking with pieces of blotting-paper, and mark each radicle at intervals of $\frac{1}{8}$ in by making transverse lines with Indian ink, beginning at the tip Pin the seedlings to a piece of wood or a cork, and invert it over a wide-mouthed jar containing a little water Fix different seedlings with the radicle pointing upwards, downwards, and horizontally From day to day observe and sketch the appearance of the seedlings, noting the direction of growth of the shoot and the root

(*b*) Grow Bean or Pea seedlings in your box with a sloping glass front. When the side-roots have grown out, mark on the glass the positions of a few of these, also of the main root, note especially the position of the *tip* of each root Then tilt the box up at an angle of about 45°, and notice how (1) the main root and (2) the side roots change their direction of growth how does the *shoot* behave ?

(*c*) What happens if a shoot, laid horizontally, is fixed so that it cannot curve upwards? Lay a few Bean-seedlings on moist sawdust and keep the shoots down with a piece of thick glass, or fix them to a sheet of cork by means of crossed pins, and set them in moist air for about six hours Then remove the glass or the pins the shoot will quickly bend upwards How can you explain this result?

(*d*) Fit a Bean-shoot into a bottle or tube of water, using a bored or split cork and sealing with plasticine, and let the shoot project horizontally Stick a pin or needle into the free end of the shoot and set up beside it a foot-rule, note the position of the index-pin on the scale After half an hour (the shoot will have made little or no upward movement in that time), turn the bottle round through 180°, taking care to keep the free end at the same point on the scale The shoot soon begins to curve *downwards*, then it comes to rest, and finally it curves *upwards* Now try to account for these results Remember that there is an interval between (1) the *perception* of the stimulus and (2) the visible *response* made by the root

273. How does Moisture affect the Direction of Growth?—Is the main root bound to grow vertically downwards in *all* circumstances, or could it be induced to change its course by some other stimulus? We know that roots require moisture Would the main root leave its vertically downward course in order to grow towards a moister part of the soil? Would this be a useful thing for the root?

* (*a*) Lay a glass jar on its side (a jar with flat sides is best) and put a sponge, soaked with water, in the closed end. Fit the jar with a cork (bored with a hole for ventilation), and to the inner side of the cork fix a Pea or Bean seedling by putting two pins through the cotyledons Fix the cork so that the root lies horizontally Does the root bend and grow towards the wet sponge, the shoot towards the mouth of the jar?

(*b*) Grow seeds in a box with a bottom of wire gauze, and hang the box up or tilt it by putting a wood block under one end. The roots grow down through the gauze into the dry air, but they soon curve and grow upwards again Why?

(*c*) Take a tumbler or jar about a quarter filled with water, tie over it some muslin, and on it place some damp sawdust with several soaked seeds, then invert a larger tumbler over the whole The roots on emerging from the sawdust do not turn back, but grow down in the damp air. Compare with (*b*)

(*d*) In the middle of a box of dry soil or sawdust place a flower-pot, first plugging the hole in it by a cork. Place some soaked seeds in the sawdust around the flower-pot, but do not water except by pouring water into the flower-pot, and filling the latter up as the water evaporates After a few days, gently pull up a seedling and see whether its root has curved towards the pot.

274. How does Light affect the Direction of Growth?—Have you noticed the appearance of plants growing near a window? The shoot grows towards the light, the stem placing its axis parallel with the direction of the light, while the leaves place their surfaces at right angles to it

* (*a*) Set some seedlings in such a position that the light falls on them mainly from one side, and notice the effect this has on their shoots After marked bending has been observed, turn the seedlings round and see whether the shoots again respond to the "attraction" of light

(*b*) Take the wide-mouthed glass jar and cover it outside with black paper or cloth, leaving a narrow vertical chink on one side. Fix a Bean seedling horizontally inside the jar, at right angles with the chink Does the root bend, and does it bend towards or away from the light? In what direction does the shoot bend?

(*c*) Pass the roots of germinated Cress, Radish, or Linseed through holes in muslin tied over a tumbler filled with water Set the tumbler close to a window, or in a box with a vertical slit in the side turned to the light, or use a black sheet, as in the preceding experiment Observe the direction in which root and shoot grow with regard to the light.

It is interesting to note that plants grown in red light often show one of the effects of darkness—their stems are usually long, but the leaves are well developed and turn green. In blue light plants develop small leaves and show very marked bending towards the source of light (heliotropic curvature), but they soon die

275. How does Contact affect the Direction of Growth?—As we shall see later, some parts of plants are very sensitive to contact, *e g.* tendrils. Has the root this kind of sensitiveness? How does the growing young root behave when it comes against an obstacle which it cannot push out of its way? The root can force itself through loose soil even when young and soft, and when it grows old and hard, becoming thicker year by year, it can exert enormous pressure against anything around it. Have you ever noticed the raising-up and splitting of asphalt-pavements around the roots of trees in towns? Have you ever seen the cobblestones of a courtyard pushed up by the growth of a mushroom-like fungus? If so, you will have some idea of the force which growing plants are able to exert

* (*a*) To the inner side of the glass in your box with glass front fix with sealing-wax small pieces of wood, some with holes bored in them, and plant seeds a little above these obstacles Notice that the roots diverge from their course only so much as is absolutely necessary to avoid the obstacles, and resume their original course as soon as they have passed one

(*b*) Another method is to use a glass funnel filled with moist soil or sawdust, plant the seeds close to the glass near the top of the funnel, and fix the obstacles an inch or more below them

(*c*) With the point of a knife remove a small portion of the yolk of a hard-boiled egg, and apply it to one side of the tip of the radicle of a Bean-seedling (choose one with a straight root about 2 ins long); fix the seedling vertically in a jar containing some water at the bottom, and keep in darkness After a few hours, see whether any curvature has taken place, and, if so, in what direction The one-sided irritation, due to the presence of the foreign substance, has evidently exerted a stronger influence than that of gravity

276. Test-Tube Experiments.—For demonstration to a class, some of the foregoing experiments may be duplicated by arranging them on a small scale in test-tubes, which are handed round the class The following will serve as examples :—

(*a*) Get a test-tube with a cork to fit, pin to the cork a Pea-seedling with a straight root 2 ins long, put a strip of blotting-paper in the tube, and run in water to soak it Fix the seedling in the tube with its root pointing to the closed end, and keep the tube in a vertical position, with the corked end uppermost

(*b*) Fix a similar seedling in a tube, but keep the tube inverted, so that the root points vertically upwards

(*c*) Get a similar seedling and tube, but with a razor or sharp knife cut off the extreme tip of the root, and keep the tube in the same position as in (*b*)

277. The Root-Tip a Sensitive Organ.—From the foregoing experiments it is clear that the root responds, by changing its direction of growth, to the influences or stimuli of moisture, light, and contact. We have also seen that the main roots always grow vertically downwards, towards the centre of the earth, except when deflected from this direction by one of the stimuli just mentioned It will be noticed that the shoot of a seedling grows towards light and away from moisture, its responses to these stimuli being the opposite of those made by the main root. The force of gravity also has a stimulating effect on the growth of root and shoot, the root responds by growing down in the direction of the force, the stem by growing up in the opposite direction

That these opposite tendencies of root and stem are to be ascribed to gravity has been determined by experiment There is a machine called the **clinostat**, consisting essentially of a plate mounted on a horizontal axis, and therefore rotating vertically A plant is attached *horizontally* to the plate, and the axis is rotated *slowly* A little reflection will show that the influence of gravity is eliminated Stem and root simply continue to grow straight onwards in whatever direction they have been placed

Another experiment is to attach a plant to a wheel which rotates *rapidly* and *vertically*. Here another force—centrifugal force—comes into play. If the opposite tendencies of root and stem are to be ascribed to gravity, we should expect similar tendencies to be exhibited under the action of centrifugal force This is the case, in seedlings fixed to the vertically revolving wheel, the roots bend away from the centre of the wheel and grow straight out in the direction of the radius, while the stems grow straight in towards the centre of the wheel.

What will happen if the wheel revolves *horizontally*? Two forces now act on the plant, the centrifugal force and that of gravity, and the root bends obliquely outwards, the stem obliquely inwards

Side-roots are but little sensitive to gravity; they grow out from the parent root, each growing in a definite direction. If the growth of a side-root is towards, say, the east, and it is interrupted by a stone, as soon as the root has reached the edge of the stone it will resume its eastward direction of growth The branches of the side-roots, again, grow away from these, and may therefore grow in a downward, horizontal, or even upward direction In the last-mentioned case, therefore, we get some branch-roots actually growing in a direction opposite to that of the main root—that is, making an exactly opposite response to the stimulus of gravity

We have also found by experiments that the attraction-stimulus of gravity may, even in the case of a main root, be overcome by the "attraction"-stimulus of moisture or by the "repulsion"-stimulus of light, while contact with an obstacle like a stone causes the root to change its direction of growth for a time, though it resumes this direction as soon as it reaches the edge of the obstacle It is clear, therefore, that the root is a sensitive organ, its sensitiveness or "irritability" being much the same as that of an animal

It is very important to understand that geotropism and other forms of irritability in plants answer to the various kinds of sensation in animals, and also to try to see the *reason* for each response made by each part of a plant to each kind of stimulus from outside it If you have carried out the preceding experiments, stop here and think out for yourself *why*—*i e.* to what advantage—the main root of a bean or pea (or other plant you have worked with) grows downwards, *why* it grows towards moisture, *why* it grows away from light, *why* a root turns off on meeting an obstacle and goes on its former course after getting to the obstacle's edge, *why* a branch-root grows away from its parent-root In each case remember the two great functions of the root (what are these?) and the need for the root-system to explore the soil thoroughly and to come into contact with as much soil as possible, in order to do its work efficiently.

The fact that the removal of the root-tip destroys the power of the root to respond to the stimuli of gravity, etc., goes far to prove that this is the sensitive region of the root, but such experiments are not conclusive, because curvatures due to the injury usually take place, the root sometimes forms a new tip, and then responds to stimuli as before

The fact that the root-tip alone is sensitive to the stimulus of gravity has been shown by the following method — Seedlings of Broad Beans are rotated on a clinostat and their roots caused to grow into small L-shaped glass tubes, open at one end, so that the root is sharply bent at about $\frac{1}{16}$ in from its tip. They are then placed in various positions, each having this small glass boot on its root If the tip is vertical and the basal part of the root horizontal (┌), *no curvature takes place*, though the radicle grows vigorously in the horizontal direction. If the tip is horizontal (L), the vertical part of the root outside of the tube bends until the tip of the root is vertical.

278. Regions of the Root.—From your observations on the growth of roots, it will be evident that the increase in length of a root is almost entirely due to the elongation of the region lying a short distance behind the root-tip, also that root-hairs only arise where the root has ceased to lengthen, and that branches only arise still farther back (*why* do not root-hairs and branches arise where the root is still growing in length?). The following regions may be distinguished in a root —(1) growing-point, covered by root-cap, (2) elongating or growing region, (3) region bearing root-hairs, (4) thickening region, which may bear branches (rootlets)

279. How is the Root-Tip protected against injury as the root pushes its way into the soil?

A little behind the actual tip of the root lies the growing-point, which is covered and protected by the root-cap The growing-point consists of cells which are constantly dividing, growing after each division, then dividing again, so as to produce new cells Most of these cells go to form the main mass of the root, but those formed towards the tip of the root add to the root-cap The root-cap is, therefore, continually renewed from within as it wears away outside, compare with this the way in which one's skin is renewed The onward growth of the root is due to the formation of new cells at the growing-point and to their elongation (and further division) behind the growing-point The growing-point is not only the factory where new cells are made, it is also the sensitive part of the root, which alone can perceive the stimuli of gravitation, etc, and by sending them on to the region behind cause the bending movements

Examine with the microscope the roots of any small seedlings (Cress, Mustard, Wheat) mounted in water on a slide Focus on the upper surface, and notice the outer layer of cells (skin-layer or epidermis) immediately behind the extreme tip Sketch part of this, then focus deeper so as to get an "optical section" of the growing-point, and try to make out the tissues as shown in Fig. 60, the root-cap covering the denser layers of cells which form the growing-point, and which gradually pass backwards into the central cylinder, the rind (cortex), and the epidermis

Trace the origin of root-hairs, each of which is a long slender tube, closed at the free end, each hair arises as an outgrowth from a single cell of the skin-layer Farther behind the root-tip the root-hairs are longer, but they are absent from the oldest parts of the root—i e those nearest the stem. Crush a root by pressing it under the cover-glass, and observe the vessels in the central cylinder; some vessels have a spiral fibre coiled inside them, others show small spots (pits), which are thin places in the wall Notice also the large cells of the rind (cortex) Try to find the beginnings of side-roots and different stages in their growth

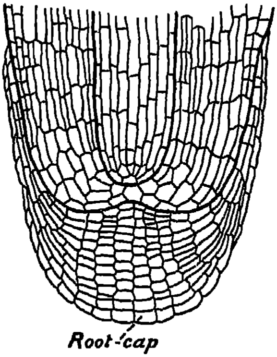

Fig 69 —The Root-Tip, in Section, magnified.

280. The Conducting Channels of the Stem.—From your study of the functions of the leaf, you should be able to draw some conclusions regarding those of the stem Some further experiments will give additional information about the part played by the stem in the process of transpiration

* (a) Place whole plants, or seedlings, or cut twigs, into water coloured with red ink, set them where the conditions are favourable for transpiration, and after an hour or so cut across the root and stem at various points. If the coloured water has risen in the stem, trace it upwards by means of successive cuts, then replace the plant in the liquid, and after a time notice its appearance in the leaves, as shown by the colouring of the veins. Note that in the root the stained veins are at the centre.

(b) Make thin cross-sections and longitudinal sections of these plants In most cases notice that the bundles are arranged in a single ring; this arrangement is found in most Dicotyledons. In Grasses, Lilies, and other Monocotyledons the red stained bundles will be seen to be scattered through the stem Notice that in most cases only the inner part of each bundle is stained In Vegetable Marrow or Cucumber the bundles are in a double ring, and here the central part of each bundle is stained.

(*c*) Place a twig of a tree—*e g* Oak, Beech, Elm, or any other hard woody plant—in the coloured water, and when the leaf-veins become coloured, cut across the stem, starting in this case at the top where the stem is soft and green At the top notice that the bundles are separate; but as we pass downwards, making successive cuts, the bundles appear to fuse and form a continuous ring.

(*d*) Cut two twigs of a woody plant—*e.g* Willow—about equal as regards length and the number of leaves. Cut round one of the twigs, a few inches from the lower end, as far in as the hard woody part, and remove from the lower part of the stem the whole of the soft outer tissue. Leave the other twig uninjured, and set both twigs into red ink Notice that the removal of the outer tissue makes little or no difference as regards the rise of the red ink in the stem and its appearance in the veins of the leaves

* (*e*) Take a Bean seedling which has been pulled up and allowed to lie for some time, till the leaves have begun to wither Place the seedling with its stem under water coloured with red ink, then cut across the stem under the coloured water. Take the stem out and notice that the water has run up, in the bundles, for some distance This shows that when the leaves are transpiring and the roots are not absorbing enough water, there is a **"negative pressure"** in the water-carrying channels, so that when the stem is cut under the coloured water the liquid rushes in

The foregoing experiments show (1) that one function of the stem is to carry water from the roots to the upper parts of the plant, and (2) that the water travels through the inner portion of each bundle when the bundles are separate and through the hard woody part of a stem when the bundles are joined to form a continuous cylinder. Through what channels do the organic substances produced in the leaves travel to other parts of the plant? If these also travel along the bundles, they must pass through the soft outer tissue in the case of a woody stem, and in that of a stem, with separate bundles, these substances must pass either through the part of each bundle which was not stained by the red ink or else through the other tissue of the stem, or by both routes Before considering this question, we must know more about the structure of the stem; but the following experiments will give a clue as to the paths by which the leaf-manufactured food travels in the plant (*f*) Place a Bean seedling or a Garden Nasturtium (try various other plants) in darkness for a few days, then remove some leaves and test them for sugar by boiling them in Fehling's solution There will be little or no red coloration, showing that sugar is absent, or nearly so Expose the plant to sunlight for several hours, then place it in darkness (after having tested some leaves, or parts of leaves, for starch), and after a time test some leaves for sugar, which will be indicated by the red colour produced around the veins If the presence of sugar is detected in this way in the leaf-blade, test sections of the leaf-stalk at different levels, to find out by what paths the sugar travels towards the stem Also test sections of the stem itself. By using Fehling's test it is easy to prove that the sugar travels in the leaf itself along the tissue surrounding the veins (bundles), and in the stem it is to be found in the ground tissue in which the bundles are embedded

(*g*) Make two cuts round the lower part of a Willow twig, about an inch apart, and remove the soft outer tissue of the stem between these cuts, so as to leave only the hard woody portion of the stem for this distance Then set the twig in water (which should be changed every day) or in culture-solution, and notice that it begins to sprout after a few days (Fig 70) Below the injury the development of buds and new roots takes place but slowly, whereas above it new roots are rapidly formed and nourished by food conveyed from the upper parts of the branch by the tissue lying on the outer side of the wood This experiment usually succeeds best in spring or early summer Later in the year it is advisable to remove the leaves in order to diminish the loss of water, since there are no roots on the cutting to keep up the supply of water The rapid development of buds and the formation of roots above the ringed part show that food passes down chiefly through the soft outer region of the stem

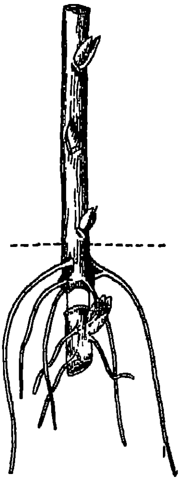
Fig 70 —A Ringed Branch of a Willow sprouting in Water

281. Chief Functions of the Stem.—The leaves must be exposed to air and light in order to carry on their work of food-making, and in this work they require supplies of water containing dissolved salts. The food made by the leaves has to be carried to other parts of the plant which are living and growing or acting as storage-organs. The roots, having no chlorophyll and not being exposed to light, cannot, of course, carry on photosynthesis, and must therefore be supplied wit organic food made in the leaves

From these considerations, and from the results of ou simple experiments, it is clear that the ordinary functions o a stem are (1) to bear the leaves and help in spreading the out to light and air; (2) to convey water with dissolve salts from the roots to leaves and other parts of th shoot, (3) to carry organic food from the leaves to othe parts These are the primary functions of the ordinar stem, but in addition to this stems often have to take o special functions Thus they may serve as organs of vegetative propagation, as store-places of nourishment, etc

282. Structure of the Stem.—In Dicotyledons, both i herbaceous stems and in woody stems when young, isolate bundles run through the stem, forming a hollow cylinder (ring, as seen in cross section), In Monocotyledons th bundles are scattered through the ground-tissue of th stem. This is because in the former case the bundles (vein which run into the stem from the leaves remain near th surface, ultimately joining bundles from other leaves an increasing in size, whereas in Monocotyledons the bundle from each leaf run deep into the stem and curve outward lower down, tapering away as they do so. Hence the bundle on the outside of a transverse section are in this case smalle than the central ones, whereas in the Dicotyledon the smalle bundles alternate with the larger ones (Figs. 71, 72)

It is important to realise that the bundles in the ste are continuous with the veins of the leaves on one hand an with the veins in the vascular cylinder of the root on the othe

(*a*) Soak the stem of a Broad Bean or Dead Nettle (try othe herbaceous Dicotyledons) for two days in dilute potash, and then fo two days in dilute nitric acid Brush and scrape away the softe parts, leaving a skeleton of the vascular tissue Note the way in whic the bundles from the upper leaves join on to those of the lower leave

(*b*) Another method of showing that the vascular bundles (veins) o the leaf are continuous with those in the stem is to cut thick longitudinal slices through the stem and the bases of the leaves, and place th slices in caustic potash.

(*c*) To observe the continuity between the bundles of the ste and those of the root, split a Bean seedling longitudinally in th part where stem and root meet, and treat with caustic potash or aniline chloride solution[1], the former makes the soft tissue transparent, the latter stains the hard woody tissue yellow.

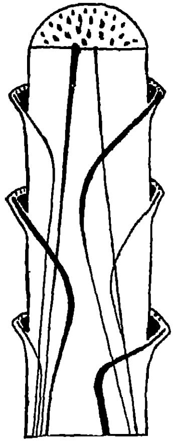

Fig 71 — Longitudinal Course of the Bundles in a Monocotyledonous Stem

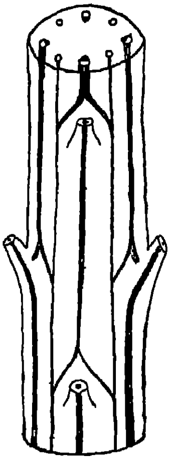

Fig 72 — Course of the Bundles in Stem of a Dicotyledon

283. The Vegetable Marrow (or the Cucumber) is one of the most suitable plants in which to study the tissues of the stem

* (*a*) Cut across the middle of several "internodes" in the older parts of the shoot, and in each piece thus obtained notice that (1) the "node" gives off a leaf, a special climbing organ (tendril), and usually either a leafy branch or a flowering branch, or both, (2) the internode is hollow, so that the stem forms a tube, with (usually) five ridges, and furrows alternating with these, (3) the bundles (usually ten) are arranged in two rings.

(*b*) Scrape gently the outer surface of the stem, and remove part of the epidermis or skin, which is thin and colourless and bears hairs, some of them large and prickly Notice the soft tissue which lies between the bundles, this is the ground tissue (*parenchyma*), and its cells can easily be seen with a lens After removing the epidermis, scrape away the soft tissue which lies below it, and notice the hard tissue, which forms a wavy tube around the stem, outside of the bundles Slit a piece of stem by two longitudinal cuts, and by scraping isolate a strip of this hard tissue (*sclerenchyma*) Bend it, pull it by the two ends, and try to split it, notice that it is easily split longitudinally, but is difficult to break by pulling at the ends This hard tissue, then, is fibrous, very strong, and it gives mechanical support to the stem, it is really a part of the ground-tissue, which has become fibrous and hard

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[1] Dissolve some aniline chloride (about 1½d. per ounce) in a little alcohol, add water to make a 10% solution, then a little hydrochloric acid A wooden match, or a splinter of wood, turns bright yellow after being dipped into the solution, which gives a ready test for woody substance (*lignin*).

(*c*) Now examine the bundles which are embedded in the soft ground-tissue within the sheath or tube of hard tissue Notice in each bundle (1) a whitish hard portion, consisting chiefly of tubes of various sizes, and occupying the centre of the bundle, (2) two greenish soft portions on the inner and outer sides of the hard portion Place a piece of the living shoot with its cut end dipping into red ink, and notice that the ink rises in the middle portion of each bundle This portion is the *wood*, and the tubes it contains are the *vessels*, which carry water upwards from the root Split a long piece of stem so as to get a strip containing a single bundle, put one end into a glass of water and blow through the other, noting the air which escapes in bubbles after passing through the vessels This shows that the vessels are long, open tubes

(*d*) Next cut across a piece of fresh stem with a dry knife or razor, and notice the juice which oozes out of the soft greenish outer and inner portions of each bundle These portions are the *bast*,[1] and they also consist chiefly of tubes, but the bast-tubes, instead of carrying water up the stem as the wood-tubes (vessels) do, carry organic food-substances from the leaves to other parts of the plant Notice that the juice which oozes out of the bast-tubes is thicker than water; collect some of it, place it on a glass slide, and test it (1) for starch, (2) for proteids, (3) for sugar To test for (1) and (2) add a drop of iodine solution, for (3) place some Fehling's solution on the slide with the juice and warm it, or collect enough juice to place in a test-tube and heat with some Fehling's solution.

(*e*) In sections through the youngest parts of the Marrow stem, notice that the ground-tissue is complete right across the stem, the cavity found in the older parts is formed by the central region of ground-tissue (pith) becoming torn as the stem grows thicker Also notice that the wood contains only the narrow spiral and ringed vessels, and that the collenchyma and sclerenchyma are not yet distinguished sharply from the ordinary ground-tissue

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[1] The Marrow, Cucumber, and some other plants are exceptional in having bast on the inner side of the wood as well as on the outer side In most stems the bast occurs only on the outer side of the wood The bast-tubes are called *sieve-tubes*, because they are interrupted by cross-walls which are perforated like a sieve (*sieve-plates*).

284. Sunflower Stem.—Cut transverse and longitudinal sections of stem of Sunflower, and compare its structure with that of the Marrow stem (see Fig 73) In the Sunflower the stem is cylindrical, not furrowed , the central ground-tissue does not become torn to form a cavity , the hard tissue (schlerenchyma) is in separate strands, one immediately outside the bast of each of the larger bundles In an old stem, notice that there is a continuous layer of wood, with a complete layer of growing tissue (cambium) on its outer side

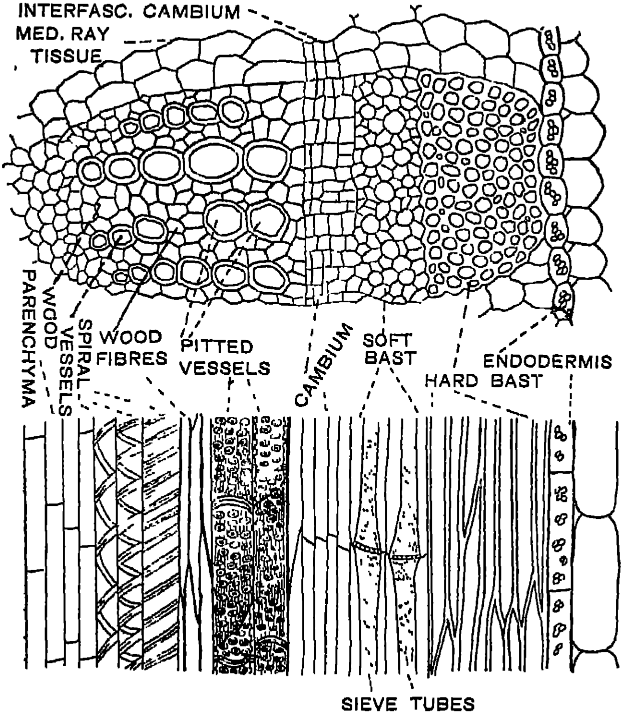
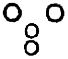


Fig 73 —Transverse (upper) Longitudinal (lower) Sections of Part of a Sunflower Stem

285. Dead-Nettle Stem.—Cut sections of stem of Dead Nettle and compare with structure of Marrow and Sunflower stems. Notice the central air-cavity ; the ring of bundles consisting of a large bundle at each of the four corners of the stem, and smaller bundles between these—*i.e.* facing the flat sides of the stem, the projecting corners containing collenchyma, the shallow air-cavity along each flat side of the stem, a little below the epidermis

286. Maize Stem.—(*a*) Cut transverse sections of stem of Maize Notice that the bundles, although "scattered" through the ground-tissue, are most crowded towards the outside, and that in each bundle the bast side points towards the epidermis and the wood side towards the centre of the stem In thin sections stained with aniline chloride, notice (1) the epidermis of small thick-walled cells, (2) the narrow band of sclerenchyma below the epidermis; (3) the ordinary ground-tissue (parenchyma) of large thin-walled cells, separated by air-spaces at the corners, (4) the vascular bundles, each with (5) a sheath of sclerenchyma

In a single bundle, notice the four conspicuous vessels arranged like a V, thus



with narrower vessels lying between, the patch of clear-looking tissue (bast) lying partly between the two larger vessels, and the more or less complete sheath of fibres around the bundle The larger wood-vessels are pitted, the smaller ones have rings or spiral thickenings. The bast, which stands out distinctly in sections treated with aniline chloride (its walls being of cellulose and therefore not stained), consists of sieve-tubes alternating regularly with narrow cells (companion-cells), but the tubes are narrow and rather difficult to make out clearly Compare the relative amounts of sclerenchyma and of vascular tissue (wood and bast) in different parts of the section It is easy to see that the hard-tissue (stained yellow with aniline chloride) is more strongly developed towards the outside of the stem

In many Monocotyledon stems the outer bundles are embedded in a layer of hard tissue which forms a complete tube, this is well shown in shrubby plants like Butcher's Broom and Asparagus Cut sections of the stems of these and of other Monocotyledons, also of the flowering stems of Lily, Hyacinth, etc In all cases the bundles are more crowded towards the outside, and the hard tissue is developed as a layer in the outer part of the ground-tissue In the erect stems of Monocotyledons, therefore, the "skeleton" or supporting tissue is disposed in the form of a tube, in spite of the "scattered" arrangements of the bundles

(*b*) Cut longitudinal sections of the Maize stem (or those of other Monocotyledons), and notice the course of the bundles. This can easily be done by cutting thick sections passing through the bases of several leaves and placing them in caustic potash for some time. In these plants, and in most other Monocotyledons, the leaves have a broad insertion, and from them a number of bundles can be traced into them Their downward course in the stem is not parallel to the surface, but curved They first run obliquely downwards towards the centre, and then bend outwards again towards the surface. After running through one or two internodes, they join on to bundles passing in from other leaves Hence at all levels we have bundles situated at varying depths in the ground-tissue, and it is for this reason that the transverse section of the stem shows a "scattered" arrangement of the bundles

287. Tissues of the Herbaceous Stem.—From the foregoing work on stem-structure it is evident that the tissues of a herbaceous stem (and the young parts of a woody stem) are of three kinds (1) epidermis, (2) ground-tissue, (3) vascular tissue (wood and bast)

(1) The epidermis consists of a single layer of cells, with thickened outer walls (cuticle), and bears stomates and often hairs It agrees closely with the epidermis covering the leaf, and is continuous with it.

(2) The ground-tissue consists mainly of thin-walled cells, those in the centre of the stem often becoming dried up and torn asunder, while those in the regions between and on the outer side of the bundles have various important functions The cells in the outer region (cortex) usually contain chloroplasts, and are supplied with air which enters by the stomates and traverses the spaces between the cortex-cells, these cells are therefore, like the cells of the ground-tissue (mesophyll) of the leaf, able to make organic substance by photosynthesis The outermost cortical cells often become thick-walled, and form supporting tissue (collenchyma) which differs from ordinary hard tissue in consisting of living cells

The ground-tissue is also modified in places to form sclerenchyma, consisting of thick-walled woody fibres, which contain no living substance but only water, and which, therefore, serve a purely mechanical function The sclerenchyma is found outside of the bundles, either forming (1) a complete tube around the whole stem, or (2) a strand on the outer side of each vascular bundle, or (3) a sheath around each bundle (what plants afford examples of these three arrangements?) The sclerenchyma of the stem is continued into the leaf, where it usually forms a supporting band below each chief vein or above it or in both positions The ground-tissue also serves for the conduction of sugar from the leaf, and for the storage of starch In Dicotyledons the new strips of cambium, which are required to form a complete ring of growing tissue around the stem, are formed in the regions of ground-tissue (rays) which lie between the vascular bundles.

(3) The most important structures in the wood and the bast are the wood-vessels and the sieve-tubes, the former serve to carry water upwards from the roots, the latter to carry organic substance, especially proteids, to the growing parts of shoot and root. The wood serves also as mechanical (supporting) tissue, it usually contains fibres and ordinary cells (parenchyma) in addition to vessels.

288. Structure of the Root.—The root, like the stem, contains vascular bundles, but the wood-bundles are separate from the bast-bundles and lie on alternate radii, whereas in the stem the wood and bast are joined to form each bundle The vascular cylinder of the root contains from two to about eight bundles of wood and an equal number of bast-bundles in Dicotyledons, while in Monocotyledons the number of bundles is generally much larger.

* (*a*) Place the root of a Bean or Pea seedling (try others as well) in some water on a slide, and scrape off the soft outer tissue (epidermis and cortex), first on one side and then on the opposite side Wash off the scrapings (using your wash-bottle), place on the scraped root some aniline chloride solution, add a drop of glycerine (which makes tissues more transparent), put on a cover-glass, and examine Notice the yellow-stained wood-vessels, and the long cells associated with them, sketch what you see.

* (*b*) Cut transverse sections of a Bean root at different levels, starting a little behind the root-tip, it is easier to do this if the root is held between two grooved pieces of elder-pith or of carrot Keep your razor wetted with 50 per cent. spirit, cut thin sections, stain some with aniline chloride, others with iodine solution

Notice the tissues shown in Fig 74, the skin-layer, many of whose cells grow out to form root-hairs, the rind (cortex) consisting of cells which are separated at the corners by air-spaces and often containing starch-grains, the central cylinder consisting chiefly of the wood-bundles (stained yellow with aniline chloride), the bast-bundles (*phloem*) alternating with these, the packing-tissue between the bundles, and the sheath surrounding the whole cylinder The inner wood-vessels are pitted, the outer ones are spiral, the latter are narrow and are formed before the inner vessels, hence the term "protoxylem" is applied to these outermost and narrowest vessels The bast-bundles consist chiefly of long tubes, called *sieve-tubes*, because at intervals each is crossed by a partition which is perforated like a sieve, so that the contents (which are proteid substances) can pass through the pores in the *sieve-plates* from one part of the tube to another. The *sheath* consists chiefly of two layers of cells (*endodermis* and *pericycle* in Fig 74), but these two layers are not very sharply marked in the Bean root The pericycle is a very important layer, because its cells remain capable of dividing and giving rise to new cells, from the pericycle arise (1) the *rootlets*, (2) part of the *new wood and bast* formed as the root grows older and thicker, (3) the *cork* which covers the surface in the older parts of the root.

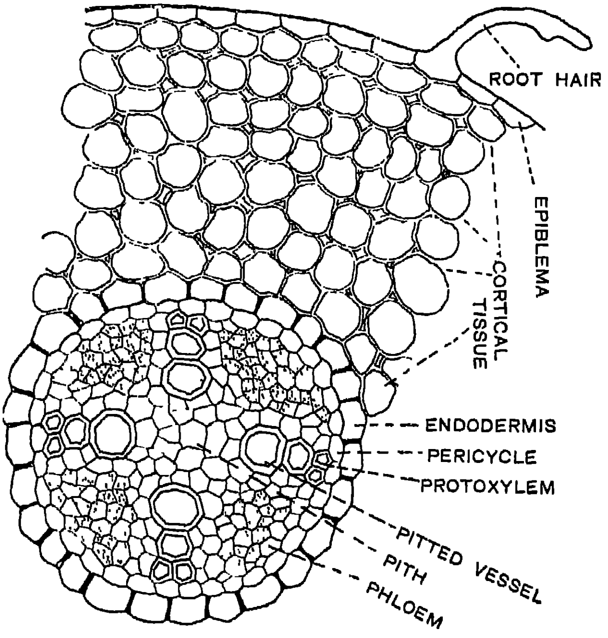


Fig 74 —Transverse Section of a Young Root of a Dicotyledon with Four Strands of Wood.

(*c*) In roots of Cress, Mustard, etc , mounted whole and stained with aniline chloride or red ink, also in sections through roots of Bean or Pea, notice the formation of rootlets as small swellings (arising from the pericycle) opposite the wood-bundles , these swellings grow out, eating their way through cortex and skin-layer, and escape as small pegs which grow into rootlets The rootlet is enabled to digest the tissues through which it bores its way, by the cells covering its tip producing ferments similar to those found in germinating seeds Do you see why rootlets are arranged in a definite number of longitudinal rows?

(*d*) In older parts of the root of the Bean and other dicotyledons new tissues are formed, and the root grows thicker This is because the cells of the sheath (pericycle) outside each wood-bundle, together with the cells of the central cylinder which lie inside each bast-bundle, divide actively and give rise to new bast and new wood

Cut cross-sections of old parts of the main root of Bean, stain with aniline chloride, and notice the new wood and bast that have been formed, the original wood-bundles (primary wood) can still be seen in the centre of the root

(*e*) In sections of the root of Maize or other monocotyledons notice the large number of wood and bast-bundles, no secondary thickening occurs in these roots

289. Continuity of Tissues of Root, Stem, and Leaf.—It is very important to realise that the tissues (epidermis, ground-tissue, vascular tissue) of the root, stem, and leaves are continuous with each other.

The epidermis of the leaf and of young stems is a protective layer, preventing excessive transpiration for instance, and where necessary it bears a layer of cuticle or of waxy "bloom," or a covering of hairs, to help in this function, another important function is to allow of the passage of gases into and out of the plant, by means of the stomates. The epidermis of the younger parts of the root serves for absorption, and to increase the absorbing surface root-hairs are developed. In the older parts of the stem and root the epidermis may be replaced by cork, which serves chiefly for protection, but allows the passage of gases through the lenticels which have the same function as stomates

The ground-tissue, which is continuous throughout the plant, consists primarily of living thin-walled cells, separated by air-spaces which form a continuous system and allow gases to circulate through the plant. In the root the ground-tissue consists of colourless cells; its chief functions are to convey water from the root-hairs to the wood-vessels, to carry oxygen to the living and growing cells of the root, and to store up food. In the stem, the outer part of the ground-tissue consists of chlorophyll-containing cells which carry on photosynthesis, especially in plants whose leaves are very small or do not remain long on the plant—*e.g.* Horsetails, Gorse, Broom, Asparagus, Bilberry. Part of the ground-tissue of the stem is usually modified to form strengthening tissue (collenchyma, sclerenchyma) The ground-tissue of the leaf is simply an extension of the green outer tissue of the stem, the cells having larger air-spaces between them, and being specially adapted to carry on photosynthesis, while the epidermis contains more stomates

The vascular tissue (wood and bast) is also continuous throughout the plant In the root the wood and bast are in separate bundles, but in the transition region between root and stem the root-bundles change in position so that the wood and bast form double or "conjoint" bundles, the wood coming to occupy the inner side of each stem bundle, twisting round so that the first-formed vessels (spiral and ringed) are nearest the centre in the stem, instead of being external as in the root The essential parts of the bundles (vessels and sieve tubes) run continuously from root to leaves, the stem-bundles bending outwards into each leaf so that the wood is on the upper side of each leaf-bundle (vein) and the bast on its lower side

We have therefore three systems of conducting channels running through the plant (1) the wood-vessels which carry water and dissolved salts, (2) the bast-tubes (sieve-tubes) which carry manufactured organic food, especially nitrogenous substances, (3) the air-passages between the cells of the ground-tissue, through which air circulates, the exchanges of gases between the atmosphere and the living plant-tissues taking place chiefly through the stomates and the lenticels

290. The "Skeleton" of the Plant.—We might compare the hard parts of the stems, roots, and leaves of a plant with the skeleton of an animal, since these hard parts support the plant and help to keep it firm and strong

Why are the hard tissues of the stem arranged in a hollow cylinder, or tube, like the pillars that support the galleries in buildings? Why are they packed together towards the centre in the case of the root, forming a tough central cord? Why are the chief bundles in the leaf-stalk arranged like the letter U in a cross-section? Why are the chief veins (bundles) of the leaflet arranged like a feather, and why do they project on the lower side of the leaflet? Why are the finer leaflet-veins arranged in a network?

Most of these questions can be answered by considering the results of simple experiments on the bending of a beam of wood (or other material) firmly fixed at one end and loaded at the other The lowering of the loaded free end is (*a*) proportional to the load, (*b*) proportional to the *cube* of the length of the beam, (*c*) inversely proportional to the breadth of the beam, (*d*) inversely proportional to the *cube* of the depth of the beam

From (*c*) and (*d*) we see at once why it is so much more advantageous to increase the depth than to increase the breadth of a beam. For when the beam is bending, the upper side lengthens and the lower side shortens, but the middle portion of the beam neither lengthens nor shortens Exactly the same applies when the beam is set upright instead of horizontally, and force is applied to it from one side Hence it is a good plan to put the hard material near the outside, and this is done in the **girder**, which is I-shaped in cross-section If we want an upright *rod* to resist bending before winds coming from north, east, south, and west, we need two joined girders crossing at right angles In such a structure the central part is clearly under little strain as compared with the outer parts, therefore it would be better to put all the material on the outside and make it into a square tube or, better, a circular tube (to resist the bending effects of winds coming from all directions)

Clearly, then, the strength of the upright structure (stem) is, *using the same amount of material*, very greatly increased if the hard material is placed *towards the outside*, *in the form of a tube* If you think over these points in the "mechanics" of plants you will see how the plant successfully meets the mechanical needs of the various parts and at the same time the need for *economy* in the amount of material used to make the parts strong enough The leaflets have to be supported and spread out to air and light, the stem has to carry the leaves and branches and has also to resist undue bending before the wind

The root, on the other hand, being embedded in the soil has no weight to support, but it has to keep a firm hold of the soil (the root-hairs help greatly in this), and it must be able to resist pulling or tugging strains. Hence the best arrangement for the root is to have the hard tissue at the centre, forming a compact cord

There is great diversity in the arrangement of the hard tissue (sclerenchyma), which is, next to the wood of the vascular bundles, the most important supporting tissue or "stereom" (hard-tissue) of the majority of erect herbaceous stems Sclerenchyma-fibres, which occur among the vessels in the wood as well as in separate bands or strands outside of the bundles, are *dead* cells (like those which make up the wood-vessels); whereas *collenchyma*-cells are living, and can carry on assimilation, and are also capable of growth, the walls not being hard and woody, as in sclerenchyma In some plants—*e.g.* Grasses, Sedges, Horse-tails—the epidermis contains flinty substance (silica) which helps in giving rigidity

Cut cross-sections of various herbaceous stems, stain with aniline chloride, and examine with lens and microscope, giving special attention to the arrangement of the supporting tissue in the vascular bundles (wood), sclerenchyma, and collenchyma Of special interest are ridged and winged stems (Gorse, Broom, Bilberry) and the stems of Grasses, Rushes, and Sedges

291. Is the "Skeleton" alone able to keep the Young Shoot erect?—What happens if you pull up a whole seedling, *e g* Bean or Sunflower, or cut off the shoot, and let it lie on the table? Why does it turn limp? Weigh a shoot after cutting it off, then weigh it after it has been allowed to wilt what has the shoot lost? How can you make the limp shoot become stiff again? Why is it useless to try to restore a shoot that has been allowed to lie too long and has become dry and withered?

292. How are Limpness and Firmness produced.—It is due to *osmosis* that the shoot turns limp, or *flaccid*, on losing water and recovers its firmness on being placed in water

* (*a*) Cut off a seedling's shoot and put it into 5 per cent. salt solution it becomes limp after a time (why?) Take the limp shoot out of the solution, wash it under a tap, and set it in water what change occurs, and why?

(*b*) Is it necessary to put the whole shoot in the salt solution? Place one fresh shoot with its cut end and another with its free leafy end dipping into the solution and afterwards into water

293. Plasmolysis and Turgidity.—The shoots used in these experiments are not killed unless the salt solution is made too strong or they are left too long in it Prove this by pulling up whole seedlings and re-planting them, after making them wilt in the salt solution

(*a*) Cut sections of a piece of fresh beetroot, mount sections separately in (1) water, (2) salt solution, (3) alcohol In (1) notice the layer of protoplasm ("primordial utricle") lining the cell-wall, and the red sap filling the cavity (vacuole) of the cell; some of the cells will be cut open, allowing the sap to escape In (2) notice that the primordial utricle contracts from the cell-wall, but still contains the red sap, which does not escape from the living cell In (3) notice that the red sap diffuses out of the cells, which have been *killed* by the alcohol

* (*b*) If you have no microscope, the following simple experiment will give you some idea of turgidity Cut a piece, about 3 by 1 by 1 in, out of a fresh beetroot, and notice the way in which it resists being bent between your thumb and forefinger applied to its ends

Then place it in salt solution, and notice that it bends much more easily (why?), then place it in water until it becomes stiff again (by the cells becoming turgid) Then place the piece of root in boiling water for a few minutes, rinse it in cold water and see whether it can be made turgid again.

294. Tension Caused by Turgidity.—Are all the cells of a growing plant equally turgid? Have you ever noticed that the cut ends of flower-stalks (*e g* Daffodil or Tulip) dipping into water become split in a peculiar way, and that the split parts curve outwards and upwards?

* (*a*) Make short slits in the cut end of a seedling stem (or the flowering-stalk of a Daffodil, Tulip, Bluebell, etc) and set it in water The curling of the slit parts is evidently due to the inner cells absorbing water more rapidly than the outer ones

In addition to the three supporting or "skeletal" tissues —wood-vessels, sclerenchyma, collenchyma—the ordinary thin-walled tissue (parenchyma) plays an important part in maintaining the rigidity of herbaceous stems as well as of petioles, leaf-blades, and flower-stalks, by the turgidity of its cells In a herbaceous stem the pith has a strong tendency to elongate, but this is hindered by the outer tissue, and the state of strain thus set up tends to keep the stem rigid and erect The outer tissue is on the stretch, tending to shorten, while the inner tissue is under compression

If a strip of Sunflower stem 50 cms long is cut out and the soft tissue (pith) separated from the outer tissue, the former suddenly lengthens to over 60 cms, while the latter shrinks to 45 cms In the same way, if we cut a turgescent stem, say of a young Elder twig, flat on two opposite sides and then bisect it, each half bends outwards, the pith and cortex assume their proper lengths, the former expanding and the latter contracting.

By finding what strength of salt or sugar solution is needed to bring about plasmolysis, we get a rough idea of the osmotic force of the cell-sap Saltpetre solutions are generally used, a 1 % solution of this salt (nitrate of potash, KNO_3) exerts a pressure of 3½ atmospheres

The osmotic pressure within living cells is often much greater than this In the pith of Sunflower it is about 13 atmospheres, that is, a pressure of 13 atmospheres would be needed to prevent the isolated pith from expanding. In the pulvinus, or motor organ, of a Scarlet Runner leaf the pressure is about 11 atmospheres, in the cambium of

296. Annual Rings of Wood.—In a cross section of a tree trunk or a thick branch,[1] a series of concentric rings (really, of course, *layers*) can be seen in the wood Each of these rings corresponds (normally) to one year's growth

The wood formed in spring has large vessels which are required for the rapid transport of water to the young leaves, and it is softer than the hard compact wood formed later in the year as the rapidity of growth decreases and the leaves transpire and assimilate less and less actively. In autumn the formation of new wood ceases, reserve foods are stored up, and the resting-buds (Ch XII) are usually by this time (about the end of August) fully developed In spring the buds open and the young leaves expand, the cambium, being well supplied with food, again begins to grow actively and to form new spring wood. The transition from spring to autumn wood may be gradual, but there is an abrupt change from the autumn wood (containing narrow vessels) of one year to the spring wood (containing wide vessels) of the next.

Various causes which bring about fluctuations in the amount of food or of water supplied to the cambium may be responsible for the occasional production of several "annual" rings in one year, for instance, an extra "ring" is formed when the early leaves of trees are damaged (by frost, cold dry winds, insects, etc) and "Lammas shoots" (more correctly "midsummer shoots") are produced

297. Rays.—Running outwardly from the centre of the stem are numerous bands, the medullary rays,[2] which serve partly for the storage of starch and oil, and partly for the horizontal conveyance of food materials and water. They also serve to bind together the successive layers ("rings") of wood, and thus make the wood compact and strong The rays are vertical plates, their height varies, but they must not be thought of as sheets of tissue running continuously from the base of the stem to the apex The rays can often be seen very plainly on a square Pine match; two opposite faces show the rays as broad, shiny, horizontal streaks (radial faces), while on the other two (tangential) faces they appear as narrow vertical streaks

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[1] Old *roots* undergo growth in thickness (beginning in a rather different way), just as stems do, and show annual rings

[2] The rays, though called medullary or pith rays, do not all extend into the pith; most of them stretch from the cambium to an annual ring (additional rays are formed each year)

298. Heart-Wood and Sap-Wood.—In old trees showing *many* annual rings, the central region of secondary wood is often distinctly marked off from the outer region This is largely due to the wood-cells losing their contents and to changes in colour and in chemical composition of the walls of the wood-vessels The central region (heart-wood) is harder and darker than the peripheral region (sap-wood)

It is almost entirely by means of the young sap-wood that water is conveyed upwards from the roots to the leaves As the wood grows older it becomes unable to act as a channel for the passage of water. Hence the importance of the addition of new layers of wood is two-fold· first, it provides a connected series of new channels for the ascent of water as the old ones become functionless; and secondly, it increases the strength of the stem as the weight of the upper portion of the tree increases.

299. Knots.—The knots which occur in wood are branches which have become surrounded by the new layers of wood produced as the stem increased in thickness Carefully examine logs of various kinds of wood, and find out all you can about the history and mode of formation of the knots

Do the knots run right through the tree-trunk from outer surface to centre? What has probably happened, and how many years ago, when the knot ends abruptly and is covered on the outer end by the new wood-layers? How does "Bird's-eye Maple" gets its name, and what are the "eyes" in its wood? Why is a knot usually much harder than the rest of the wood, and why does it fall out readily from a plank or board?

300. Cambium.—The chief function of the cambium is to produce new tissues. The cells of the cambium-layer are living and capable of active growth and division, the new cells formed being mostly converted into new "water-tubes" new "food-tubes," and new fibres, while some remain unaltered (beyond growing in size and changing in shape) and add to the living cells present in wood, bast, and rays.

The shoot is continually growing and producing new leaves and buds, so that year by year the number of leaves is becoming larger. This involves a yearly increase in the weight of branches and leaves to be supported and spread out to light and air The branching of the root means a continually growing area of absorbing surface, in the form of root-hairs, in the soil, and since the root can make no organic food to supply its increasing needs, more and more leaf-manufactured food must be conveyed to it

All this means an increasing demand for more wood-tubes to conduct water and salts from the roots, more bast-tubes to conduct organic food from the leaves, more strengthening tissue (fibres, which act solely as strengthening structures, and wood-tubes, which serve this purpose in addition to that of conduction), and more tissue in which food can be stored (*e g* the rays)

It is obvious that this important zone of growth is most favourably placed in the plant It is well protected from external influences, and well supplied with necessities of life On its immediate inner side are the wood-vessels along which the water and inorganic salts pass from roots to leaves, while touching it on its outer side is the bast through which manufactured food materials are sent for distribution throughout the plant Moreover, running through the cambium are the medullary rays, from which it can draw supplies of food when, as in early spring, no new food is being made by photosynthesis

Besides the functions mentioned above, the cambium plays other parts under certain conditions. It is involved in the processes of **pruning, budding, grafting,** propagation of plants by **cuttings** ("slips"), and in the **healing of wounds** on the stem (Ch XXV.)

301. Cork and Bark.—It is evident that the internal formation of secondary wood and bast must exert considerable pressure on the outer tissues, which are stretched and eventually ruptured. To provide for this there is the formation of new tissue from a growing layer developed in this region This layer is the **cork-cambium.** In the majority of cases it arises in the outermost layer of the cortex, immediately below the epidermis The young cells given off to the outer side of the cork-cambium form the **cork.** This tissue, being impermeable to water, cuts off the epidermis from nourishment. The epidermis dies and peels off as the first bark of the tree The cork is developed to replace the epidermis and carry on its functions

302. The Bark may be defined as the dead tissue lying outside an active cork-cambium We have already indicated what the first bark consists of The first cork-cambium formed may persist for a large number of years, or even throughout the life of the tree. In such cases, *e.g.* Birch, Beech, there may be a considerable formation of bark owing to the dying off of the older cork-layers. But in most cases this first cork-cambium dies, sooner or later in those plants where it has a superficial origin, early in those where it is deep-seated. It is replaced by a new cork-cambium developed in the deeper tissue. This produces a new cork-layer, and as a result all the outlying tissues (the original cork, etc.) die and are added to the bark. If the succession of secondary cork-cambiums is rapid, it often happens that the cork comes to lie close to the bast, and in some cases the new cork may even arise *in* the bast, *e.g.* Vine and Clematis.

In some trees the bark comes away in sheets, and is spoken of as **ring-bark.** This may be due either to the first cork-cambium being persistent or to the successive cork-cambiums appearing in the form of regular rings. But in most trees the bark is given off in scales (**scale-bark**), this is due to the fact that the secondary cork-cambiums do not arise as regular rings or layers, but in the form of curved strips.

303. Lenticels.—In the young green shoot the epidermis has stomates allowing for the free entry and exit of gases. When the cork-tissue is developed we usually find certain structures known as lenticels, which usually form small oval patches on the surface of the shoot. In Birch the lenticels are long, transverse, and very conspicuous on the white bark. Sections show that at these points the cork-cells are not in close contact, but have separated from each other and form a loose powdery mass through which gases can readily pass (Fig. 75).

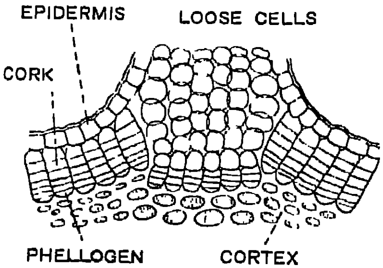

Fig. 75.—Section through a Lenticel. Phellogen = Cork cambium.

These lenticels are as a rule developed immediately underneath the stomates. Where a thick mass of cork is developed they form long passages or canals, filled with the powdery cork-cells, as, for example, in the ordinary cork of commerce.

The lenticels are closed in winter by the formation of ordinary compact cork-tissue. There are air-spaces between the cells of the cortex and of the medullary rays, so that all the living tissues are aerated by way of the lenticels.

304. Practical Work on Woody Stems.—

(*a*) Cut sections of twigs of Elder, Willow, Elm, Oak, or other trees, and notice in the youngest parts the separate bundles arranged in a ring. In the older parts note that the continuous cambium has produced a solid mass of wood on its inner side, while the surface of the stem has become covered by a brown coating of *cork*. Peel off the cork, and notice the green cortex, then a zone of colourless tissue (bast), which is separated from the hard wood by a moist sticky layer (the cambium). Cut sections and stain some with aniline chloride, others with iodine. In the wood, notice the rays and the "rings." Look for trees showing stages in healing of wounds where branches have broken off. Compare the wood of various common trees; make a collection of polished slices. Find out all you can about timbers—density, hardness; uses, "silver-grain", "burrs", "shakes"; canker, dry rot, and other diseases, etc.

(*b*) Next cut a thin slice out of the thickest part of a branch with a saw, and rub down one of the cut surfaces on fine glass-paper until it is very smooth. Examine it with the aid of a lens, and note the parts as indicated in the preceding paragraphs (Arts. 295-303). Examine logs of wood showing the cut surfaces, or the cut stumps of trees in a wood or plantation.

(*c*) Strip the cork-layer from twigs of Elder and other plants which show lenticels plainly on the surface, and notice that lenticels are not merely surface-marks, but that they pass right through the cork to the green cortex-tissue. Strip off, layer after layer, the bark of a Birch twig, and notice that the lenticels go through all the layers.

(*d*) Dip a twig of Elder, Birch (or other plant which shows lenticels plainly) into boiling water, and notice the air-bubbles which escape from the lenticels. This shows that the green outer tissue of the stem has air-spaces, and that gases can pass through the loose lenticel-tissue.

(*e*) Fix one end of a cut twig (about 4 ins. long) of Elder or Birch securely into the short limb of a J-tube; seal the free end by covering it with plasticine and then tying on a piece of stout rubber tubing, folding the latter over and again tying it to the twig. Put the whole into a jar of water, so that the twig is below the surface, and pour mercury into the long limb of the tube; air-bubbles escape from the lenticels.

305. Forms of Stem.—In some plants the aerial portion of the stem is very short, so that the leaves seem to spring from the top of the root, while arising from the centre of the tuft of leaves is the upright flowering axis. Such leaves are often said to be radical, and the condensed portion of the stem, together with the upper part of the root, is known popularly as the "root-stock." Very commonly this is perennial, and forms flowers and new tufts of leaves year after year, as in the Plantain, Daisy, and Dandelion.

Most stems grow in the air, but many are buried in the soil. Some are soft (herbaceous), others hard and woody (chiefly in *arboreous* or *arborescent* plants, *i.e.* shrubs and trees). In our later studies we shall find that the stems of plants assume an immense variety of forms in connection with special adaptations.

Many plants produce special branches which serve for vegetative propagation, *i.e.* multiplication apart from seed-formation. This is especially common among low-growing or "ground-hugging" plants.

Runners are long slender branches which grow along the surface of the soil. They are easily studied in Strawberry, Daisy, Sweet Violet, and Coltsfoot. In the House-leek and various Crassulas the runners or "**offsets**" are short, and carry out large rooting buds from the parent plant.

The "**suckers**" of Rose, Raspberry, and Mint are lateral branches arising below the level of the soil, which grow upwards to form subaerial stems bearing leaves and flowers. The underground portions of such stems resemble roots, and are white or pinkish in colour. Their true character can, however, be told by their axillary exogenous development, and by the occurrence of scale-leaves upon them. In some cases (Roses and Poplars) the suckers arise endogenously from roots, but the growing apex soon becomes like that of a stem.

306. Underground Shoots are commonly used for the storage of food, and they may serve either for the maintenance of the life of the individual when the parts above ground are killed by winter frosts, or for the production of new individuals by vegetative propagation. They may be distinguished from roots by the fact that they bear leaves or buds, and by their origin from buds borne in the axils of leaves or leaf-scales. The four chief types of underground shoots are Rhizomes, Tubers, Corms, and Bulbs.

307. The **rhizome** is a stout or slender stem, which usually grows horizontally a short distance beneath the surface of the soil. Stout and partially upright rhizomic stems are sometimes termed "root-stocks," but they can be distinguished from roots by the fact that they bear leaves and buds, as well as by their internal structure. Usually only small brown membranous scale-leaves arise directly from the rhizome, the green foliage-leaves being borne upon erect aerial shoots. Numerous adventitious roots are present, which grow out mainly from the under-surface of the rhizome, and usually near to the bases of scale leaves—that is, from the "nodes." Rhizomes often branch to a slight extent, and each branch when separated, either artificially or by the decay of the older parts, is capable of forming a new plant.

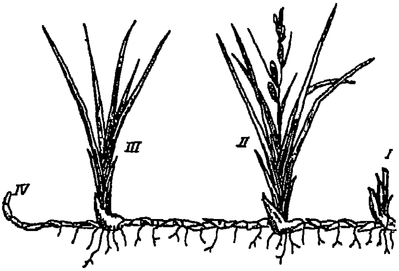

Fig 76.—Rhizome of Sedge (Carex) in Summer
Flowering shoots of (I) last year, (II) this year, (III) next year, (IV) year next but one

Year by year a rhizome travels to fresh portions of the soil, often slanting upwards, but in that case the new parts are dragged down to the same depth by the contraction of the roots.

As examples, you should study the rhizomes of various Grasses (*e.g.* Couch-grass) and Sedges (Fig. 76), Iris, Solomon's Seal, Wood Sorrel, Wood Anemone.

308. The **stem-tuber** is a swollen underground stem containing stored food-materials and bearing buds. Examples are afforded by the Potato and the Jerusalem Artichoke.

Examine tubers of Potato, also whole plants freshly dug up Plant tubers in soil and in sawdust, keeping some in darkness and others in the light

Do any of the tubers show at one end a stalk or the withered portion of a stalk? Notice the "eyes" each eye is a small outgrowth sunk in a pit on the surface of the tuber. Carefully examine one of the larger eyes. is it a solid body, or does it bear any appendages? What do you think the eye *is*? Are the eyes scattered all over the tuber uniformly, or are they more numerous at one end of the tuber? Can you make out that the eyes are crowded at the end furthest from the remains of the stalk which attached the tuber to the parent plant? If so, we may call one end the "eye end" or "bud end" or "growing end," the other the "stalk end" or "barren end" Have the eyes any definite arrangement on the tuber, or are they scattered anyhow over its surface?

Try to determine the position of the eyes by fixing a pin in each eye and joining the pins by a piece of thread The eyes are arranged in a spiral, the sixth eye being in a straight line with the first, the thread in going from the first to the sixth eye goes around the tuber twice. Compare this arrangement with that of the buds on an Oak twig and of the leaves on a Wallflower

Plant tubers in the garden or in pots, some in moist sawdust, some in moist soil, some in water, some in damp air in covered vessels, some with the bud end upwards, some with this end downwards, some cut in two, separating bud end from stalk end, some cut into several pieces with an eye or without an eye After a week or two, when the buds begin to sprout, it will be easy to tell the bud end from the stalk end Will the buds sprout if a tuber is kept in darkness? Do all the specimens gain in weight? Which do not? In the case of specimens that gain in weight, where does the extra material come from? In the case of specimens grown in darkness, at what stage do they die? In what other respects do specimens grown in darkness differ from those grown in the light? Why do tubers with sprouting buds turn soft? Chop up some sprouted tubers, shake up the pieces in water, then filter, and test the filtrate for (1) starch, (2) sugar

In examining plants grown from tubers, note that the new tubers are simply the swollen ends of branches, which can be traced back to the lower part of the stem and arise from it in the axils of small leaves. In seedlings it is easy to make out that the tuber-bearing branches come off above the cotyledons, so that the tubers are not roots, being developed above the root-system. Why are potato-fields ridged, with the plants occupying the ridges? Why is the soil heaped up around the plants? What happens if you do not "ridge" a Potato-plant in the garden? Have you ever seen tubers growing in the *air*, in the axils of foliage-leaves? What happens if you cut off the underground tuber-bearing branches?

Cut across a Potato tuber, and test with iodine solution. Put a drop of water on a glass slide and dip a cut piece of tuber into the water: notice the small white starch-grains which escape from the opened-up cells of the tuber and become suspended in the water. If you have a microscope, examine the grains, some of which will show delicate lines corresponding to thin layers built up around the first-formed portion of the grain. Do the lines run evenly around the centre of the grain, or are they closer together at one end? These starch-grains are formed from sugar, by the activity of small colourless protoplasmic bodies called leucoplasts, distinguished from the *chloroplasts* found in green parts by containing no chlorophyll and by being unable to build up sugar and starch from carbonic acid.

Compare the results given with the iodine test in very young and small tubers with the starch-content of larger tubers. Compare the taste of (1) very young tubers, (2) fully developed tubers, (3) tubers which have sprouted and given out well-grown shoots. Test tubers in these different stages for sugar with Fehling's solution. Does the tuber contain any other kind of reserve-food besides starch? Shave off a very thin slice from the outer portion of a tuber and test it with iodine: the outer layer contains *proteids*. Note the layer of *cork* which forms a skin over the tuber; if this is shaved off, a new layer is formed. What is the use of the corky skin?

309. The **corm** is a shoot whose basal stem-portion becomes swollen and filled with food-materials after flowering has taken place. The corms of two or three years often stick together so as to produce what may be regarded as a condensed form of rhizome bearing axillary buds either laterally (*Colchicum*), as in a creeping rhizome, or on the upper surface (*Crocus*), as in the upright type to which the name of "root-stock" is often applied. The swollen portion of the corm is packed with food-materials, and bears a few brown scale-leaves.

The buds develop in spring into erect flowering shoots at the expense of the stored food-materials, while adventitious roots arise from the base of the bud and also from that of the condensed stem Later in the year, when flowering is over, the new supplies of food-material, together with any remaining in the old corm, are stored up in the basal portion of the flowering shoot, which swells to form the new corm The old corm shrivels up, and a bud arising from the new one forms the flowering shoot of the next year when winter is over, the life history being repeated in this manner from year to year.

Additional buds may sometimes develop in the axils of the outer leaves, each producing a new corm, and these subsequently separate and form new plants, the same process occurs in bulbs

310. The **bulb** only differs from the corm in the relatively smaller size of the stem, and in its investment by thick fleshy leaves, which contain large stores of reserve food As in the corm, adventitious roots arise from the base of the stem, which usually assumes a discoid shape In scaly bulbs (Lilies) the fleshy scales, of which the bulk of the bulb is composed, simply overlap at their margins, whereas in tunicated bulbs (Onion, Hyacinth) the outer leaves are large and completely ensheathe the inner portions of the bulb The coloured membranous covering on the outside of such bulbs is formed by the shrivelled remains of the leaves of a previous season

Bulbs, tubers, and corms afford a means of perennation and also of vegetative propagation They occur most commonly in the group of Monocotyledons See Ch XXIV.

311. Spines.—In many cases stems becomes metamorphosed into **spines** which terminate in a hard, sharp point instead of in a bud or soft growing-point Many of the branches of Sloe, Hawthorn, etc, become modified into special protective organs of this nature That they are really branches which have ceased to grow and whose tips have become hard and sharp-pointed is indicated by the fact that they arise in the axils of leaves, and that they may bear lateral buds or even small foliage-leaves. Such spines possess a central cylinder of vascular tissue, which is continuous with that of the stem, as can be seen when they are torn off

Spines may also be developed either from entire leaves or from the edge of the blade The branched spines of the Barberry are modified leaves, for in their axils buds are present which may develop into leafy branches or flowering ones Moreover, the same Barberry plant (Fig. 77) is often found to exhibit intermediate forms between leaves and spines

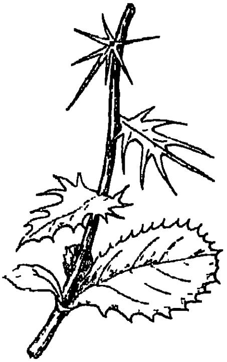

Fig 77 — Branch of Barberry, showing transition of Foliage leaves into Spines

The foliage-leaves of the garden Acacia (*Robinia*) have a pair of spines which arise at the base of the leaf-stalk, and these are really modified *stipules*. The thorns of the Gorse (*Ulex europaeus*) are either modified branches or modified leaves, for some of them bear buds in their axils, and are distinctly narrow-pointed leaves, whereas others form the hard sharp-pointed ends of branches.

312. Prickles and **Hairs** may be scattered irregularly over the surfaces of plants, the former mainly on the stem, but the latter on the stem, leaves, and roots Hairs may assume a variety of shapes, but they are always derived from he layer of cells forming the epidermis, or first outer skin, f plants, and hence they fall off when cork is formed. The Stinging Nettle has several kinds of hairs, the largest of which are the stinging hairs The point of the stinging hair s formed by a sharp, thin, brittle scale of silica, which breaks ff in the skin, leaving a tiny wound into which the acid uice contained in the hair is squirted by the contraction of he swollen base.

Hairs are frequently glandular and often sticky In the tter case they are of use as a protection against obnoxious eeping insects, which are frequently caught and retained y the glutinous secretion The leaves of a few plants, such s the Butterwort (*Pinguicula*) and the Sundew (*Drosera*) have actually acquired the power of partially digesting insects which are so unwary as to be captured in this manner

Prickles such as those of the Rose are usually classified as "emergences" This term is merely a conventional expression for all irregularly situated outgrowths from stems or leaves of constant occurrence and definite shape, but which are neither hairs, roots, branches, leaves, leaflets, nor stipules, and which neither bear buds in their axils nor arise in the axils of leaves Emergences arising from the stem usually contain no vascular tissue, and hence, when removed, they leave only a superficial wound (as in Roses and Brambles) Each of the stalked glands on the leaf of Sundew, which are also regarded as emergences, contains, however, a strand of vascular tissue arising from one of the veins of the leaf.

Prickles, of course, serve to protect the plant from the attacks of herbivorous animals, but they often do more, especially when they curve downwards as they do in the rose and bramble, for in this case they are so many hooks that help to support the stem, and therefore assist the plant in climbing among the surrounding bushes and herbage.

An acquaintance with plants in their habitats teaches us that the formation and development of hairs, spines, and prickles depend to a great extent on external conditions Thus, the same plant that produces these parts when growing in a poor, dry soil fully exposed to the rays of the sun, becomes a much softer and less aggressive character when grown in a rich, moist soil Under the former circumstances the plant not only protects itself from herbivorous animals, but also, by converting some of its buds and leaves into spines, reduces the amount of its foilage, and thus economises its scanty supply of water.

Many succulent plants, however, which grow in dry situations, such as the Stone-crop (*Sedum*) or the House-leek (*Sempervivum*), show but little or no tendency to form hairs, prickles, or spines, since they have other means of checking transpiration (thick cuticle, etc). The Rest-harrow (*Ononis arvensis*) has no spines when grown in rich, moist soil, but in dry, exposed situations most of the branches end in hard, sharp points

The hairs present on the stem and leaves are always cutinised, and usually almost impermeable to water. They serve to protect the plant, and especially the young growing organs, from an excessive loss of water. Hairs when thickly set also help to protect sensitive growing organs from excessive illumination, which retards their growth and may injuriously affect them Similarly, a close covering of hairs is of some importance in retaining heat during the night and thus keeping the plant warm, while hairs are also of great value in preventing the surface of the plant from being wetted by rain The hairs borne by the root (root-hairs), on the other hand, have no cutin, and are very permeable to water

QUESTIONS ON CHAPTER XI

1 Explain how you would investigate the rate of growth in length of a root, indicating the precautions you would observe in conducting your experiments Illustrate your answer by a diagram

2 Describe simple experiments to show by what paths water travels through the plant from roots to leaves

3 What are the main functions of roots? How are they adapted to carry on these functions?

4 How is the radicle of a seedling enabled to penetrate stiff soil? How may the force exerted by the radicle be measured?

5 How can it be proved that the direction of growth of a root is a response to the stimulus of gravity? Explain the term "geotropism"

6 How is the direction of growth of a root affected by moisture? Why is it advantageous to the plant that the stimulus due to moisture is able to overcome that due to gravity?

7 Describe the structure of the stem in any Monocotyledon, as seen in longitudinal and in transverse sections.

8 In what features of structure and function do the vessels of the phloem (sieve-tubes) differ from those of the wood?

9. What is the vascular bundle? Of what parts does a vascular bundle in the stem of a Dicotyledon consist, and what are their respective functions?

10. Explain the structure, as seen in transverse section, of a twig of any Dicotyledonous tree.

11 State generally what is the composition of a vascular bundle Describe the longitudinal course of the vascular bundles in the stem of any Dicotyledon

12 What is the cambium? Explain where you would find it in the stem of a tree, and what is its importance

13. What is meant by a "vessel"? What are the differences between the vessels of the wood and those of the bast?

14 What is a "growing-point"? What is the difference between the growing-points of stems and those of roots?

15 Describe the way in which the stem of a Dicotyledonous tree grows in thickness, and explain how it is that its wood shows annual rings

16 The stem of an Oak tree continues to grow in thickness so long as the tree lives, whereas the stem of a palm-tree does not grow any thicker when once formed. Explain the cause of this difference

17 Along what tissue does the sap ascend in a stem in its passage from root to leaf? How would you endeavour to prove by experiment the truth of your statement? What other movement of liquid substance takes place in plants besides the ascent of the sap, and what is the path of this current?

18 Explain as far as you can the way in which water is absorbed from the soil by the roots, and the transpiration current maintained, in the case of trees.

19 What is meant by sclerenchyma? Give some account of its mode of occurrence in stems, and show how it is of use to the plant

20 Describe the process of secondary thickening as seen in the root of a Dicotyledonous tree What advantages does this secondary thickening confer on the tree?

21 Describe in the case of any seedling you may select how the structure characteristic of the root changes into that met with in the young stem What do you think is the use of the change to the plant?

22 What method, other than watering, would you use to recover a plant, growing in the open, which had become flaccid from loss of water? Give reasons for the method adopted

23 Describe accurately an experiment which you have seen in which the rate of growth of roots or shoots was measured Which part of the root grows most rapidly in length, and which part absorbs most water? What advantages do plants gain by the increase of their shoots and roots in length and thickness?

24 How is the direction of a root's growth affected by light? How does a shoot differ from a root in this respect?

25 How is the growth of a root-tip affected by contact with a hard obstacle?

26 How can it be proved that the root-tip alone is sensitive to the stimuli of gravity, light, etc?

27. In what part of a root does growth in length occur? How can it be proved that the curvatures in response to stimuli (gravity, light, moisture, contact) also occur in this part?

28 Describe the characters of the various regions of a root, starting from the extreme tip

29 State all you know about the roots of land-plants, and in particular mention any observations you have yourself made on the roots of any plants.

30 Give an account of the influence of Light, Gravity, and Moisture on the growth of roots

31 Describe carefully how you would fit up an experiment which would show clearly the effect of light on the direction of growth of the stem and root of a seedling State briefly the *other* effects of light on plants.

32 What is meant by Geotropism? Write a careful account of any three experiments you may have performed in order to investigate the nature of geotropic phenomena in roots

33 Write a short account of the distribution of mechanical tissue (stereom) in the stems of plants, illustrating your answer by reference to particular cases

34. Very strong solutions of certain salts make plants wither; very weak solutions of the same salts are recommended for making them grow How would you determine by experiment how strong and how weak solutions must be to produce these effects? How do you explain the contradictory results?

35 Describe the structure of a young root as seen in transverse section. What peculiarities in its structure are characteristic of the root?

36. If a leaf or a flower-stalk is removed from the plant and allowed to remain in dry air, it becomes flaccid and can no longer support its own weight. Why is this? Give experiments in support of your explanation.

37. How would you show whether it is the reaction produced by light, or by gravitation, or by both, that causes a stem to grow upwards and a root to grow downwards?

38 Mention an experiment which shows that organic substance formed in the leaves travels down the stem outside the cambium

39. Show, by describing and drawing one example, that the branch of a tree may preserve a record of past seasons in its bark and wood.

40. Suppose you carefully pull up a young bean seedling, and fasten it by means of a pin through the seed to the edge of a shelf, so that the axis of the plant is in a horizontal position, and then keep the air round the plant saturated or nearly saturated with moisture How will the plant behave during the next few days? Describe any experiments you have made bearing on such occurrences, and state what inferences you would draw from them

41 What is meant by osmosis, diffusion, turgor, transpiration? How is the rigidity of a succulent flower stalk affected by placing it (*a*) in water, (*b*) in a strong salt or sugar solution? How would this treatment affect a living cell?

42. Draw from memory, and carefully describe the structure, as seen with the naked eye, of a block of oak (or of any other tree with which you are familiar) cut so as to include both the centre of the tree and the bark.

43. Describe the young main root of some named plant Where does most rapid increase in length occur, and how can it be demonstrated? Draw a transverse section taken a little way above the region of most rapid growth

44. Draw diagrams of longitudinal sections of a root and of a stem. Include the apex and the characteristic lateral appendages in each case Minute structures, not readily seen with a hand-lens, need not be represented

45 Give a short description of the root-system of a young dicotyledonous plant Enumerate the more important functions discharged by roots, and explain how the roots are specially adapted to perform these functions.

46. The trunk of an Oak tree, when in full leaf, is sawn all round so deeply as to cut through the sap-wood. State and explain the effect of this operation.

47 Describe the features seen in a cross-section of a piece of wood (*e g* of oak or ash) when examined with a lens. Illustrate your answer by means of a diagram

48 Explain the nature and mode of origin of "knots" and of "silver grain" in timber

49 What is meant by a Medullary Ray? Where are medullary rays found, and what are their uses?

50 When the trunk of a dicotyledonous tree is cut across, the wood is seen to be disposed in rings Explain this fact, and indicate its relation to the age of the tree.

51 Why does a succulent flower-stalk or petiole lose most of its rigidity when cut and in want of water? Could you produce this condition artificially without exposure to the air? How would you attempt to restore the rigidity of a stalk thus artificially wilted? Give reasons for your answers.

52. Describe and explain the changes that may be observed when a turgescent shoot is bisected longitudinally, and when the halves are placed successively in water and in strong salt solution

53 The split stalks of cut flowers have been found to become limp in salt-solutions containing 32·5 grammes of salt per litre, but to become turgid in solutions containing 3 25 grammes per litre Assuming these facts and given a quantity of the strong solution, how would you most rapidly prepare a series of solutions of intermediate strengths so as to determine what strength of salt solution would just suffice to cause the freshly split stems to become perceptibly limp?

54. Explain why it is easier to split a piece of wood in the direction of the grain than across it

55. Give an account of the structure and uses of Lenticels.

56 Describe and explain as fully as you can the appearance assumed by a tree growing in a position fully exposed to the wind from the sea.

57 How would you distinguish between (*a*) a simple leaf and a cladode, (*b*) a compound leaf and a short branch, (*c*) a slender underground stem and a root?

58 What are the chief points on which you would lay emphasis in a lesson on Turgescence? By what experiments would you illustrate the lesson?

59 Explain fully what is meant by Bark, and state the various ways in which it may be formed

60 Describe carefully, with diagrams, five plants which reproduce themselves without the aid of seeds. Distinguish carefully between those cases in which food is stored up and those in which it is not. Point out also at what stage the new individuals become separated from the old.

CHAPTER XII.

BUDS.

313. Buds.—Before the young stem branches, it is in most cases easy to see that between the base of each leaf and the upper portion of the stem there is a young bud (*axillary* bud or side-bud), which may grow into a shoot bearing leaves only, or flowers only, or both leaves and flowers The apex of the stem is usually occupied by a *terminal* bud (end-bud).

Buds appear as little prominences on the outer surface of the stem, and are produced by outer tissue, whereas secondary roots arise from *within* Each bud consists of a short "condensed" stem in which the "internodes" are undeveloped, so that the young leaves are closely packed together The formation of a bud depends on the fact that the slowly-growing end of the shoot elongates less than the leaves which it has produced, and these bend over its tip and protect it The apex of the stem of the bud is occupied by a growing-point, which grows and elongates when the bud opens, since it is not exposed to friction against the soil, there is no need for any such structure as the root-cap, which covers and protects the growing apex of the root

314. Brussels Sprout.—To get a good idea of bud-structure, first examine some Brussels Sprouts (1) Pick off the leaves one by one, starting from the outside, and note that each leaf has a small bud in its axil How do the inner leaves differ (in size, form, texture, colour) from the outer ones? How may these differences be accounted for? (2) Slice down through the middle of another sprout, and notice the conical end of the stem, with small outgrowths at its extreme tip, these outgrowths are the youngest leaves. Below these are older leaves, gradually becoming distinctly divided into blade and stalk, lower still come leaves whose blade is folded between the veins In the axil of each leaf is a small bud, resembling a miniature sprout, some of these buds may be cut through in the slice (if not, make more slices). Notice the strings (veins or vascular bundles) in the stem of the Sprout. Sketch a good clear longitudinal section, at least the natural size (3) Cut a series of *cross* sections, beginning at the top of the Sprout and proceeding to the base; lay the sections out in order, then compare and sketch them. (4) Set a Sprout with its cut end in red ink, and after a time cut slices and notice the bundles which extend nearly to the extreme tip of the stem and give off branches to the leaves and buds. (5) Remove most of the larger outer leaves, and notice that the inner ones soon become wilted if the sprout is set in a dry place (6) Weigh (*a*) an entire sprout, (*b*) one from which all the large outer leaves (which overlap and protect the young inner ones) have been removed; set both in a dry place, and in a few hours, or a day, weigh again and compare the loss in weight in the two cases.

Lettuces and Cabbages may be used in addition to Sprouts Why are the inner leaves softer and lighter-coloured than the outer leaves? What other differences do they show?

315. Winter-Buds (Resting-Buds).—In cold climates the buds formed at the close of the year do not develop at once, but remain dormant after the leaves have fallen When a resting-bud is about to be formed, the last foliage-leaves on the shoot sometimes grow in the ordinary way, but the stem stops growing and these leaves enclose the young leaves formed inside the bud Naked resting-buds of this kind occur in herbaceous plants, their structure being essentially like that of a Brussels Sprout, Lettuce, or Cabbage, but only in a few woody plants (shrubs and trees), *e g* Ivy, Bittersweet.

In most woody plants, however, the bud is covered by special scales (*bud-scales*), each representing a leaf or part of a leaf and being usually thick, hard, corky, gummy, resinous, or hairy, and these scales protect the delicate and sappy young leaves within from injury by rain and frost, but especially from loss of water. In cold weather the roots are hardly able to absorb any moisture from the soil, so that loss of water at such a time, when there is little or no transpiration-current flowing up in the stem, would be fatal to the young shoot inside the bud When a cold dry east wind comes after the buds have expanded in spring, the young leaves are often killed, whereas an equally cold but moist westerly wind hardly affects them

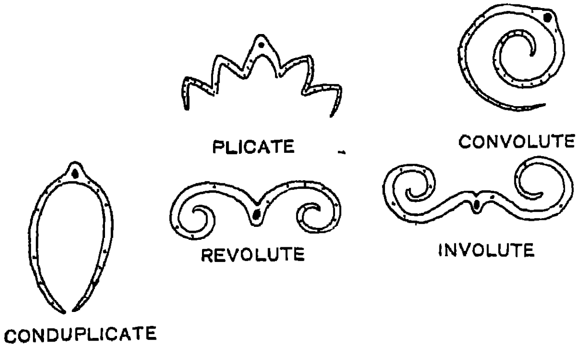

Fig 78 —Vernation of Leaves.

The scales of resting-buds may represent whole leaves (Privet, Lilac), leaf-bases without stalk or blade (Sycamore, Horse Chestnut), stipules of leaves which develop a blade (Alder, Elm, Hazel), or stipules of leaves which do not develop a blade (Oak, Beech)

316. Folding (Vernation) of Young Leaves.—To ensure the close packing of the leaves in the bud each one is usually rolled up longitudinally (more rarely rolled up transversely), but sometimes the leaves are nearly flat, *e g* Privet, Holly, Ivy, Willows Dealing only with longitudinal folding, the leaf may be simply doubled on itself along the midrib (Fig 78, *conduplicate*), or it may be pleated so as to resemble a fan (*plicate*), or the edges of the leaf may be rolled inwards (*involute*) or outwards (*revolute*), or the leaf may be rolled up from one side, so that one leaf-margin is within the coil and the other outside (*convolute*) The young leaves are conduplicate in Cherry, Rose, Elm, Hazel, Oak, Lime, Ash; plicate in Maple, Sycamore, Birch, Beech, Hornbeam, involute in Poplar, Apple, Pear (also in Violet), revolute in Plane and Rhododendron (also in Docks); convolute in Plum and Sloe (Blackthorn).

317. The Opening of the Bud.—In spring or early summer the winter-bud resumes its development The young shoot grows and lengthens, pushing aside the bud-scales, which then fall off. Since each scale leaves a scar on the lower part of the bud-axis and this part remains short, a series of closely-set scars is left on the stem A series of bud-scale-scars ("girdle-scars") is of course seen at the base of each branch, and by examining a twig and noting these series of scars we can easily tell how much the twig has grown each year, often for many years back, later on these marks are obliterated by the formation of bark, but in smooth-barked trees (*e g* Beech) one can trace the growth back for thirty years or even more by these girdles of scars

As the bud-axis elongates, the leaves grow in size and spread themselves out (the leaf-stalks of course helping in this, if present), becoming spaced out on the young shoot Buds then appear in the axils of the leaves, and these may either develop at once or after remaining dormant for a time, some of them of course becoming the resting-buds for next year's growth

It is easily understood why *all* of the axillary buds do not usually develop into branches, for if they did the foliage would be too closely packed together, and sufficient light and air could not reach all of the branches and leaves As we shall see later, trees differ very much in their mode of branching and in the arrangement of their leaves, thus in the Horse Chestnut and the Beech the outer leaves are densely packed together, so that buds within the crown of foliage have but little chance of developing into leafy branches, owing to the small amount of light which reaches them In the Birch and Larch, however, the foliage is more open, and the buds nearer to the stem have perhaps as good a chance of developing as the buds at the tips of the branches. These points will be illustrated by the various common trees which we shall study

Whenever any of the branches are pruned away or broken off by high winds or by the weight of snow, buds develop which would otherwise have remained dormant, and in this way trees are able to rapidly fill up gaps in their canopy of foliage So also pollarded willows soon form a crown of new shoots, and many of these arise from deep-seated buds, or from *adventitious* ones The latter are buds which develop out of their normal order, or without any relation to the leaves Adventitious buds may be formed not only upon the stem, but also on roots or leaves. Some Begonias are artificially propagated by placing sliced leaves on damp soil; buds appear on the wounded edges, strike root, and develop into new plants Adventitious buds may appear on the roots of the Hawthorn, Dandelion, and other plants, and may give rise to leafy or even flowering shoots For example, the roots of the Hawthorn, if chopped into small pieces and covered loosely with damp soil, produce buds and ultimately new plants Most people are familiar with the fern-like shoots produced when the top of a Carrot (partly stem, partly root) is cut off, scooped out, filled with water, and hung up by strings, try this simple experiment for yourself

318. Sycamore (see Art 599)[1]—Examine twigs at different times of the year, noting the arrangement of the leaves, and therefore of the axillary buds, in crossed pairs, forming four rows on the stem (Fig 79) The twigs are, in the younger parts, grey-green to yellow-brown in colour and are dotted with small lenticels The leaf-scars are shallow,

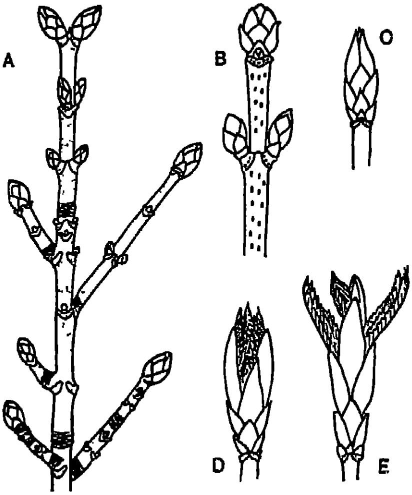

Fig 79 —Twigs of Sycamore and Stages in Opening of Bud.

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[1] If you do not know these trees in their winter aspect, cut twigs and put them into bottles or jars of water and keep them in a warm room, in many cases the buds will open, since warmth hastens growth In this way you can study very conveniently the unfolding of buds (sketch the stages observed) and at the same time identify unknown trees or shrubs by the leaves in many cases

V-shaped, with three slight projections (bundle-scars) The buds are egg-shaped, with four projecting ridges owing to the boat-like form of the bud-scales The scales, which are arranged in opposite pairs, overlapping each other regularly, are greenish below and brown at the tips and around the edge The large end-bud, which generally has two small side-buds just below it, frequently contains an inflorescence in addition to young foliage-leaves

Dissect a bud, carefully removing the parts and laying them out on a sheet of paper Note that there are six or seven pairs of scales altogether, though only four or five pairs are, as a rule, visible on the outside of the bud How do the inner scales differ from the outer ones in colour and texture? Examine the tips of the scales do any show here a small undeveloped leaf-blade, with three or five lobes? To what part of an ordinary foliage-leaf—the leaf-base or the leaf-stalk—does the bud-scale correspond? Note the young foliage-leaves in the centre of the bud how many are there visible, and what portions of the leaf are already developed? Note the fan-like manner in which the young leaf-blade is folded, try to cut out from a sheet of paper a model of the young blade Is the young leaf smooth and bare, or has it any protective covering of hairs?

Cut buds through, some longitudinally and some transversely, to see how the leaves inside are folded up

In spring, notice how the buds swell up Make careful observations on the opening of the buds It is possible to cause them to open in winter by setting a cut twig in water and keeping it in a warm room Notice how the inner scales, as well as the young foliage-leaves, expand and lengthen, pushing aside the outer scales, and how the young leaves unfold themselves The buds open at end of April or early in May

Make notes and sketches of all the stages in the opening of the bud Note that the stalks of the young leaves, which have hitherto been very short (how does this prove that the bud-scales are leaf-bases and not stalks?), rapidly lengthen and carry out the leaf-blades beyond the scales Note that the lower part of the stem of the bud hardly lengthens at all, so that when the bud-scales fall off they leave a number of crowded scars, while the upper part of the bud-axis grows out to form a long or short shoot, the leaves becoming spaced out (in pairs) upon it

Now look backwards along the twig, to find the place where *last* year's end-bud was how does this enable us to see exactly how much the twig grew each year, at least for several years back? Why is it that a series of these "girdle-scars" or bud-scale-scars is always found at the base of a side-twig, where it joins the parent-twig? Does a twig always grow equally long, or bear an equal number of foliage-leaves, every year? In the case of a horizontal branch, which buds grow into the most vigorous (as regards length of stem and number of leaves) twigs—the upper ones, the lower ones, or those on the flanks of the branch? Why do you suppose the horizontal branches differ in this respect from those which are erect or nearly so? If you recall your studies of the work of leaves, you will probably conclude that *light* is the chief factor concerned, but you should stop and think the matter out. If you cut off a horizontal branch and set it erect in water, how do the four rows of buds behave after opening?

At what time of year are the resting-buds *formed*? Can you see any trace of them, in the axils of the new leaves, just after the bud has opened and the young shoot has grown out? Notice how the buds grow in size during the summer.

Is it possible to cause the young buds to grow out at once instead of resting until next spring? Try the effect of pulling off the leaves from a twig; the buds may thus be caused to grow out a year before the proper time. This precocious growth of buds is sometimes seen in the Sycamore and several other trees, owing, in some cases at least, to external causes (*e.g.* a late period of wet weather preceded by a dry early summer and followed by a mild autumn, or the early dying of leaves through dry cold spring winds, or attacks of insects), or simply to excess of food; these "Lammas shoots" are often seen on Oaks, Beeches, Horse Chestnuts, etc. In these cases leaves which had arrested their growth in order to form bud-scales resume growth and become foliage-leaves, bearing resting-buds in their axils.

319. Horse Chestnut (see Art. 603).—The arrangement of leaves and buds on the stem, and the general structure of the buds, are the same here as in the Sycamore. The twigs (Fig. 80) are thick, smooth, grey or brown, with conspicuous lenticels. The large leaf-scars vary from being shield-shaped to half-moon-shaped, with scars of from five to nine bundles. The uppermost bud is generally larger than the others and contains a young inflorescence in addition to young leaves, but the true end-bud is often missing and represented by the saddle-like scar of the fallen inflorescence.

The buds are egg-shaped, pointed, brown, shiny, and sticky. Remove the hard concave scales, which are more or less cemented together by the sticky substance. Note the arrangement of the scales in pairs, set at right angles to form four rows; the two lowest (outermost) scales are smaller than those of the next pair, and those are again smaller than the third pair; then come two or three pairs of still larger scales which cover the top of the bud. Within these we see a pair, or two pairs, of soft greenish sticky scales, each often having at its tip five little lobes; then come the foliage-leaves, covered with down and folded up. While dissecting the bud, keep dipping it into alcohol to make it less sticky and easier to examine. How many young leaves are visible? In the large uppermost buds the axis is prolonged above the young leaves and bears numerous young flowers in tufts.

When the bud is about to open it swells up considerably, then the scales become loosened, the inner scales grow up and bend outwards, and the young leaves emerge with the leaflets (how many to each leaf?) erect, each leaflet being folded along the midrib and the side-veins as well. As the leaf-stalk lengthens (the leaflets are sessile on its end), the leaflets spread open and bend downwards Later, the leaflets rise up again and spread out horizontally, meanwhile the stem of the bud has been growing in length. The bud-scales fall off; the white hairs covering the leaflets become brownish and fall away.

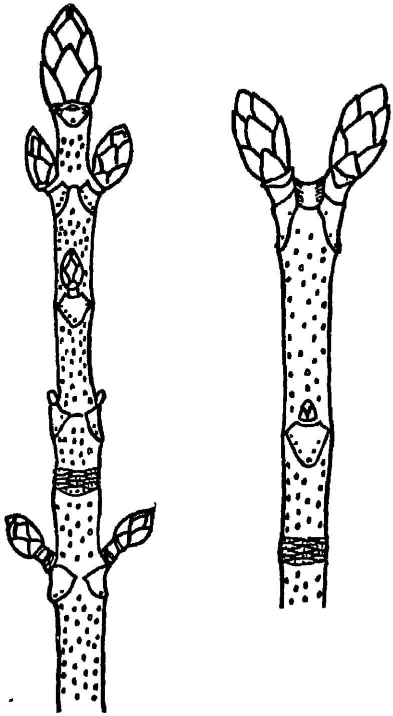

Fig 80.—Twigs of Horse Chestnut.

Here, as in Sycamore, it is easy to see, as the bud opens, that the structures lying between the hard, externally visible scales and the young foliage-leaves are intermediate in nature between bud-scales and ordinary leaves. The buds usually open about the middle of April.

320. Oak (see Art. 593).—Here the leaves and buds are arranged singly and spirally on the grey or brown twigs (Fig. 81). In passing from any leaf, or bud, to the next one directly above it, we go twice round the twig and pass four

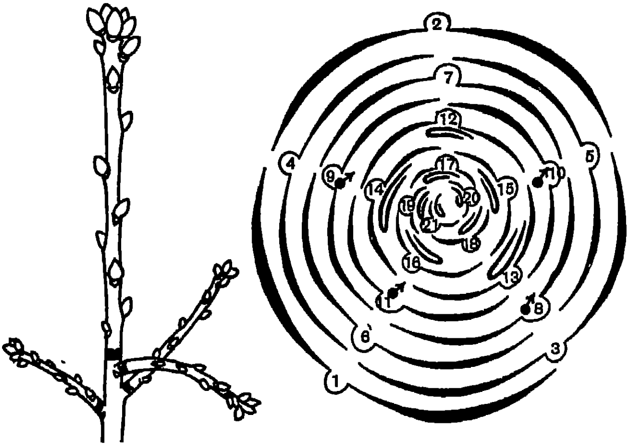

Fig. 81.—Twig of Oak and Ground-plan of Bud

other leaves, or buds; there are therefore five rows of leaves, as can generally be seen on looking along the twig. The buds, which are crowded at the tips of the twigs, are brown, smooth, egg-shaped, and slightly five-angled. The clustering of the buds towards the tip of each twig is of course simply due to the upper leaves being clustered in this way so as to form a rosette. The leaf-scars are small and triangular, with numerous bundle-scars; the lenticels are small.

Examine a bud and notice that it begins with a few tiny thick scales at the base; then come about twenty thinner scales, arranged in five rows and becoming more delicate, as well as narrower, as they pass inwards. Then come the young foliage-leaves, the outer ones are very small, each being flat and standing between two stipules, while the inner ones are larger and folded along the midrib (conduplicate); and finally come small ones again in the centre of the bud. Careful examination shows that the bud-scales, after the two lowest, are arranged in pairs; this fact suggests that these scales are *stipules*, and, by observing the opening of the bud and also the way in which the bud is formed, one can prove that this is the case Towards the end of the summer the last leaf-structures to be formed are stipules, which persist and become the outer bud-scales; the uppermost complete leaves are crowded and each forms a bud in its axil The buds open in May

As a rule, the lower resting-buds on a twig remain dormant, and do not open in the spring of the year succeeding that in which they are formed The Oak is a light-loving tree and tends to have its leaves in rosettes at the tips of the branches so as to catch as much light as possible Taking the case of a complete flower-containing bud, as soon as the bud-scales become loosened the male catkins, which arise in the axils of the upper bud-scales, grow out first and hang downwards, then come foliage-leaves (each with a young resting-bud in its axil), then leaves with groups of female flowers in their axils, and then again leaves with axillary buds After the young shoot has grown out of the bud, the resting-buds towards its tip generally open in late summer, forming a second generation of leafy shoots ("Lammas shoots").

321. Scots Pine or "Scotch Fir" (see Art 610) — Each twig (Fig 82) shows, as a rule, an end-bud with a few (usually 3 or 4) side-buds just below it and forming an apparent whorl One or more of the side-buds may be replaced by a seed-cone (Fig 82, B) The buds open about the middle of May

Examine a bud and note the very numerous (100 or more) scales, covered with whitish resin and arranged spirally Each scale (except the lowest ones) bears in its axil a small bud, so that the resting-bud of a Pine is clearly a "compound bud"—a bud of buds. The lowest scales (those without axillary buds) are hard and remain at the base of the young shoot into which the resting-bud grows Each of the other scales is at first green below and membranous above, with pointed tip and fringed edges, but when the resting-bud opens the base of the scale hardens and the upper part falls off

The axillary buds on the "compound" resting-bud are the buds of the dwarf shoots which are so characteristic of Pines Each bears about ten scale-leaves which form a sheath around two young foliage-leaves ("needles"), set face to face

When the resting-bud unfolds, the pairs of green needles emerge from the axils of the scales as the shoot grows out, the needles grow in size, and the scaly sheath persists around the base of each two-leaved dwarf shoot. When the shoot stops growing in length, it shows at the tip a terminal resting-bud and a circle of lateral resting-buds just below it, ready for next year's growth The lateral resting-buds grow out just like the terminal one, at first growing more or less parallel with it but later bending away from it

322. Larch (see Art. 612)—The brown buds, covered with resinous scales, are found at the end and also scattered along the sides of the long shoots, which are green to brown, angular, and furrowed, the lateral buds are seen (in winter) in the axils of the leaf-scars, each of which is on a projecting leaf-cushion and shows a small bundle-scar

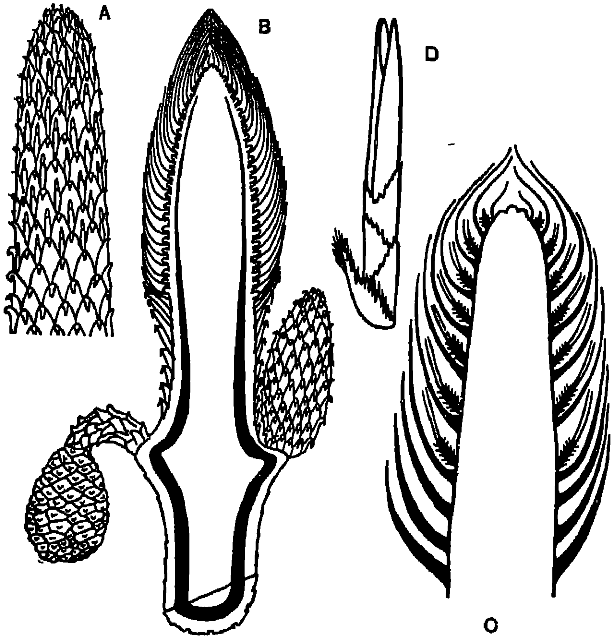

Fig 82.—Scots Pine

A, Bud beginning to open, B, Longitudinal Section of End Bud (a Side-Bud is shown on right, a Cone on left), C, Diagram of Longitudinal Section of Bud, D, Young Dwarf Shoot.

Note that the end-bud of a long shoot is egg-shaped, while the side-buds are nearly globular. Each of the dwarf shoots—the short stout branches so characteristic of the Larch—has a bud at its end (Fig 83) The bud-scales have fringed edges, the outer scales are triangular and the inner ones thinner, broader, and more rounded, then come the narrow green foliage-leaves

When the bud opens, the more delicate inner scales fall off, but the harder outer ones persist, and the light-green leaves grow out. Then the end-bud and some of the side-buds below it grow out to form long shoots, while the others remain short and form dwarf shoots. Dwarf shoots may repeat the process year after year, only elongating about ⅛ inch or so each year, or they may at any time suddenly grow out to form a long shoot. The dwarf shoots only differ from the long shoots in having a very short stem with crowded leaves, instead of a long stem with leaves spaced out singly on it. The buds open about the middle of April, the flowers appear a few weeks earlier.

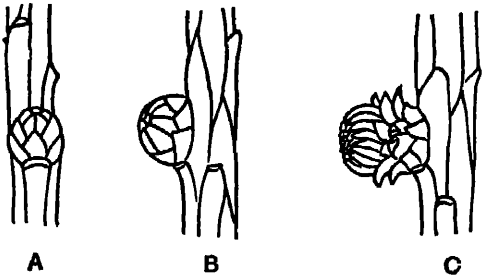

Fig 83.—Larch.
A and B, Resting bud, C, Bud beginning to open.

QUESTIONS ON CHAPTER XII.

1. How can you distinguish by the aid of bark, buds, and general appearance between any six native British trees in winter?

2. Describe, with sketches, the stages seen in the opening of a Horse Chestnut bud in spring.

3. Why are the buds of Scots Pine called *compound* buds? Describe the structure and mode of opening of a Pine bud, giving sketches.

4. Explain why one can tell how much a Pine branch has grown each year.

5. How can you tell the nature of the bud-scales in different trees? Give examples.

6. How can you *hasten* the opening of buds? Which buds have you succeeded in getting to open before they would have opened out of doors, and how long before in each case?

7. Describe, with sketches, the external appearance of a branch of Sycamore or Horse Chestnut, explaining all the features shown

8 Explain how one can tell how much a Sycamore or Horse Chestnut branch has grown each year

9 Describe a branch of Oak as seen in winter Why do the buds tend to be crowded at the tip of the branch?

10 Describe various ways in which the young leaves are protected in the bud Why are they usually folded up? Give examples and sketches

11 What kind of plant produces Brussels Sprouts? What *are* the sprouts, and in what position do they stand on the parent plant?

12. Describe the buds of Larch, and the way in which they unfold

13 Why are Willows and Poplars "polled" or "pollarded"? What is the effect of this operation on the growth of the tree?

14 Why do not *all* the buds on a tree branch open in spring? Why do some buds produce long shoots and others very short ones? How could you make a short shoot (dwarf shoot) of, say, Beech grow into a long shoot?

15 Describe the structure of the winter-bud of one of our trees, and explain what happens in the spring when it expands into a leafy shoot

16 Make outline drawings of the leaves and describe the appearance of the bark of any five British trees Mention the time of flowering in each case

CHAPTER XIII.

FLOWERS AND THEIR WORK.

323. The Work of the Flower.—We have already examined the Broad Bean flower, and we have seen that after a time nothing is left of the flower except (*a*) the "young pod," which becomes greatly enlarged and contains the seeds, and (*b*) the calyx, which remains as a cup round the bottom of the pod Evidently the great work of the flower is the production of seeds Are any other parts besides the pistil concerned in this work, and, if so, what share do they take in it? You have noticed the yellow powder (pollen) which is produced in the anthers and is set free when they open, and which is then found inside the keel and on the upper parts of the pistil (style and stigma) Has the pollen anything to do with the production of the ripe pod and its seeds? Would the pistil grow into a fruit, with seeds, if no pollen came into contact with it?

324 Effect of removing the Anthers.—Flowers which have not yet opened must be used in these experiments, because the anthers burst and shed their pollen at an early stage Remove the anthers, making sure that you pick off the whole number, and that none of them have burst already To prevent pollen from reaching the pistil from another flower, tie a small bag of paper or of fine muslin over the antherless flower, which must, of course, be allowed to remain on the plant If the removal of the anthers has been carefully done, the flower will open much as usual Treat several flowers in this way, in case any damage is done which might throw doubt on the results. Are any seeds formed? Leave some of the antherless flowers uncovered do any of these produce seeds?

325. Effect of removing the Stigma—You will have noticed pollen adhering to the upper part of the pistil, *i e* the style, especially to the tuft of hairs and the little terminal process (stigma) just above it. Is this end part of the style the only part capable of receiving pollen? Open young flowers (with the same precautions as before) and remove the upper part of the style, cutting just below the tuft of hairs, cover some of these stigmaless flowers with small bags, and leave others exposed Does this affect the result? To meet the objection that the removal of the stigma causes injury which might account for the result, try the effect of opening some young flowers and covering the top of the style with a small bit of plasticine

326. Pollination.—The foregoing experiments show that ripe seeds are not produced unless pollen comes into contact with the upper part of the style—that is, unless pollination occurs Will pollen from the anthers of the same flower suffice, or must the pollen come from another flower?

(*a*) Cover a young unopened flower with a paper or muslin bag, and see whether seeds are produced Treat several flowers in this way, so as to have a number of results on which to base your inferences

(*b*) Place pollen on the stigmas of newly opened flowers, using a fine brush, dip the brush into boiling water before using it again each time (to kill any pollen left on it) In some cases (A) place on the stigma pollen from the anthers of the same flower, in others (B) bring the pollen from another flower on the same plant; in others (C) bring it from a flower on another plant In the two latter cases (B and C) the flower's own anthers must be removed before they have opened

Simple experiments like these show that the Broad Bean can be **self-pollinated** (Art 329), although self-pollination does not (in the author's experience at any rate) occur so freely in this plant as in various other cultivated plants of the Bean family (Sweet Pea, Garden Pea, etc) In the latter plants, in fact, pollination regularly occurs before the flower-bud opens, so that abundant seed is set in the entire absence of insect-visitors

327. The Essential Organs.—It is now obvious that the only parts of the flower directly concerned in, and essential to, seed-production are the stamens and the pistil. The lowest seed-plants (*e.g.* Pine, Larch, Yew, Cycads) have their young seeds exposed (on flat scales in most cases) to the air, instead of being formed within a closed chamber or seed-vessel, as in the Bean; and the stalks of the stamens cannot be considered as essential (they remain undeveloped in some plants) The essential structures appear, therefore, to be the anthers and the "young seeds" We know that in the Bean, as in other seed-plants, these "young seeds" do not develop into mature seeds, but perish like the rest of the flower, unless pollen-grains are placed on the stigma.

328. Fertilisation.—In what way does the pollen-grain induce the "young seed" (*ovule*) to develop into a mature seed? What happens when a pollen-grain is placed on the stigma? We cannot give a full answer to these questions unless we study the minute structure of the parts concerned [1]

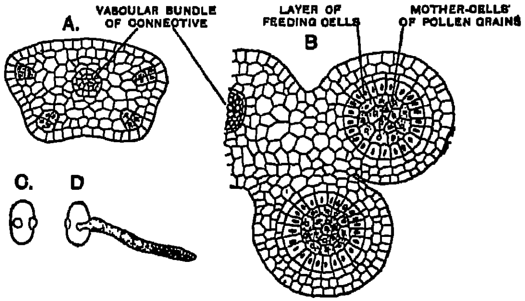

Fig 84 —Broad Bean A and B, Cross-sections of Young Anthers, C, a Ripe Pollen grain, D, Pollen tube

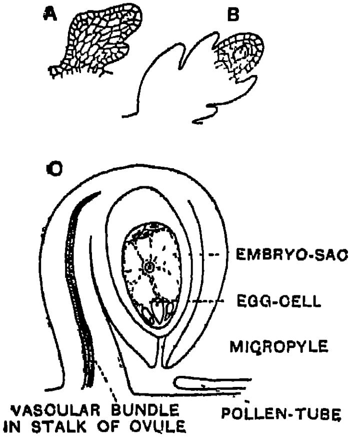

Fig. 85.—Development and Structure of Ovule ("young seed"), Longitudinal Sections

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[1] Preparations of specimens showing fertilisation and embryo-formation are included in the *Plant Biology Set of Micro Slides*

In each ovule a cell, the *egg*, is produced When the flower has opened the stigma becomes wet and sticky, so that pollen-grains are held on it Each pollen-grain grows into a long fine tube which burrows down through the style and eventually enters the little opening in the ovule and its tip touches the egg-cell, which lies close to this opening, embedded in the ovule (Figs 84-6) The pollen-tube opens, and a male cell passes from it to the egg-cell and fertilises it, *i e* fuses with it Then the fertilised egg develops into the young plant (embryo), the part just outside of the embryo also grows to produce the endosperm, which may or may not be absorbed by the embryo before the seed ripens, the seed being non-endospermic ("exalbuminous") in the former case, endospermic ("albuminous") in the latter.

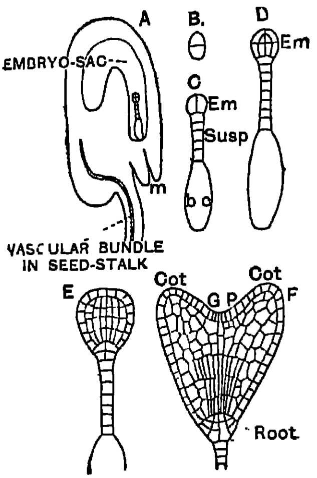

Fig 86.—Development of Embryo in Shepherd's Purse

A, Young Seed (treated with caustic potash) showing Embryo at micropyle-end of curved Embryo sac, m., Micropyle, B-F, stages in growth of Embryo, G P, Growing point of Stem, Susp, Suspensor, b c, Basal Cell, Cot., Cotyledon, Em, Embryo

(*a*) Examine the stigma of a Tulip (or other flower with large stigma), and see whether it is wet If so, shake over it some powder, *e g* flour or chalk, and then try to blow the powder off. Place a stigma on your tongue, and see whether it is sweet Place a few stigmas in some Fehling's solution in a test-tube, and heat (test for sugar).

(*b*) Place some water in watch-glasses and add different amounts of sugar, so as to get solutions varying in strength from 5 to 20 per cent. Into each place some pollen, try various plants In the case of the Broad Bean and the Sweet Pea a 10 per cent. solution is about right, and in an hour, or even less, you will see a slender thread growing from some of the grains, this is the pollen-tube, which resembles a root-hair in appearance (Fig 84, D). If you have a microscope, fix a ring of cardboard or of plasticine on a glass slide; put a drop of sugar solution on a cover-glass, dust some pollen in it, then invert the cover over the ring The drop will hang into a closed chamber, thus preventing evaporation, and the growth of the pollen-tubes can be observed

(c) The development of the embryo is easily followed in the Shepherd's Purse, a very common weed which flowers nearly all the year round Pick flowers from which the outer parts are falling or have just fallen Open the young fruit and remove the young seeds to a slide, then cover them with a few drops of caustic potash solution By teasing the seeds with needles, or pressing them under a cover-glass, it it easy to isolate the embryos Sketch the stages observed (Fig 86)

329. Self-Pollination and Cross-Pollination.—In the Broad Bean, as in many other plants, it is found, on making experiments in artificial pollination, that it is better if the pollen comes from a flower on another plant of the same species (*cross-pollination*) than if it comes from the anthers of the same flower or from those of another flower on the same plant The two latter cases are very similar in their results, and may be both included under the term self-pollination When cross-pollination occurs, the resulting seeds are generally more numerous or heavier, and give rise to stronger offspring (superior in height, weight, fertility, etc) than is the case when self-pollination occurs

In self-pollination there is a mixing of practically similar characters, while in cross-pollination there is a mixing of more or less dissimilar characters, especially when the plants that produce the male and female cells live far apart and under different external conditions Also, any useful variation is likely to be transmitted and even strengthened when cross-pollination occurs There is, therefore, an obvious advantage to the species in securing cross-pollination, and we find many adaptations, some of them very remarkable, which favour cross-pollination and hinder self-pollination (Art. 346).

In most fruit-trees the advantages of cross-pollination are so marked that the practice has arisen of never planting more than two consecutive rows of the same variety of apple, pear, or similar fruit, for practical growers well understand that the best results are generally obtained from orchards containing many varieties.

330. How Pollen is Carried.—Pollen-grains have no power of spontaneous movement When the anthers are above the stigma, self-pollination may occur (if the two are mature at the same time) by pollen simply falling on the stigma, but for cross-pollination the grains must be carried to the stigma of another flower by water, wind, or animals. Water-pollination occurs only in water-plants, and only in a few of these In this country insects are probably the only animals concerned in carrying pollen from flower to flower, but there are foreign flowers which are pollinated by birds (especially humming-birds), bats, and even snails

331. Mechanism of Broad Bean Flower.—Here cross-pollination is brought about by bees, which may be seen at work on the flowers if you watch plants growing in the open during fine weather Wind-pollination is out of the question in this case, since the stamens remain enclosed in the keel.

When a bee alights on the flower it stands on the two wing-petals, which bend down under the weight of its body Since the wings are jointed with the keel, the latter is also pressed down. If you carefully watch the bee at its work, or imitate its action by pulling down the tip of the keel, you will see that when this happens a mass of pollen is brushed out of the keel by the tuft of hairs on the style, and the stigma projects from the keel as well Some pollen is deposited on the bee's hairy body, which also rubs against the stigma, if the bee has visited another Broad Bean flower previously, some pollen will probably be left on the stigma When the bee leaves the flower the keel rises to its former position, and the process may be repeated a few times when other bees visit the same flower.

Notice the long "tongue" (proboscis) which the bee pokes into the lower part of the stamen-trough below the free stamen It is easy to see this if you pull off the standard and carefully watch the next bee that comes to the flower What does the bee find here? If you take a newly opened flower, remove the calyx and corolla, and pull apart the stamen-trough and the pistil, you will notice the liquid which has collected at the bottom of the trough around the base of the ovary. By tasting, or by the Fehling's solution test, one finds that sugar is present in this liquid—the honey, or *nectar*—which is produced by gland-cells at the base of the stamen-trough

The bee is guided to the flower, in its search for honey, by the white corolla (easily distinguished among the foliage, and made more conspicuous by the velvety black spot on each wing-petal) and also by the fragrant odour which is emitted by the petals

The coloured streaks on the standard help to guide the bee to the opening below the free stamen, but its removal does not prevent a bee from finding this opening, as can easily be seen by making the experiment These conspicuous streaks and spots are called "honey-guides"

Since the honey can only be reached when the keel is pressed down with some force, and is produced at the bottom of the tube formed by the stamen-trough (closed above by the free stamen and the standard), it can only be reached by an insect with a heavy body and a fairly long tongue The flower is specially adapted to the visits of bees It is also visited by butterflies and moths

Sometimes a bee when working at the flowers may be seen to bite through the calyx-tube and insert its tongue through the hole thus made, thus reaching the honey without entering the flower in the "proper" way, *i e* from the front Many other "bee-flowers" (*i e* flowers specially adapted for bees' visits) show neat round holes bitten out by the bee in its short cut to the honey, of which it robs the flower without rendering any service in return

332. Functions of the Calyx.—The calyx has three important uses in the Bean-flower (1) It protects the inner parts of the young flower In the bud, the stamens and pistil are enclosed in the keel, the wings are folded over the keel, and the standard over the wings, and the calyx is wrapped over the outside of all (2) When the flower opens, the corolla expands, pushing aside the calyx-lobes, then the standard curves upwards, and the flower is ready for the visits of bees. The calyx then serves to hold the petals together and prevent their falling apart (3) The calyx also protects the young fruit to some extent from becoming dried up

The calyx often assumes other functions, *e g* the attraction of insects (Monkshood, etc.), seed-dispersal (many Composites).

333. The Parts of the Flower.—The outer floral parts, exclusive of the stamens and carpels, constitute the **perianth**, which may either be single or, more commonly, double If the outer series of parts in a double perianth are distinctly differentiated from the inner, we term the former the **calyx** of (usually) green sepals, and the latter the **corolla** of (usually) coloured petals In some flowers with a double perianth, it is hardly possible to distinguish between the sepaline and petaline parts (*e g Narcissus*) Some flowers, however, have a perianth which is composed of a single ring or series of parts only, while others are naked and have no perianth at all

The perianth forms the non-essential part of the flower, whereas the stamens and carpels are the essential organs, and one or both of these must be present to constitute a flower A "typical" flower possesses sepals, petals, stamens, and carpels arranged in single or double alternating rings, each ring containing the same number of similar parts, but frequently the parts are arranged in a spiral, especially the stamens. Flowers which have no carpels are said to be "male" or staminate, those without stamens are "female" or carpellary (pistillate).

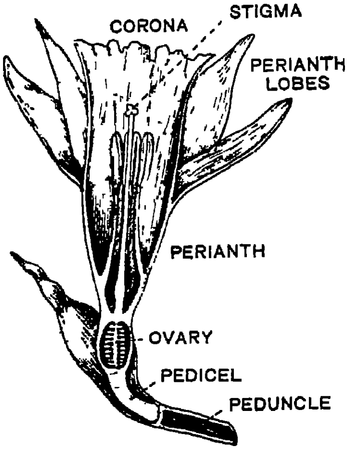

Fig 87—Flower of Daffodil in Vertical Section

334. Perianth —This term is sometimes used to include the calyx and corolla together, but more often it is applied to the flower envelope when there is no distinction, or very little, in colour and texture between the outer and inner parts of the envelope. For instance, the perianth of Tulip and Bluebell consists of six similar coloured leaves, free from each other (*polyphyllous*) or only slightly joined at the base In Lilies and Hyacinths the perianth is *gamophyllous*, consisting of a lower tubular part and six free lobes. In

Daffodil and Narcissus, besides the tube and the lobes there is a collar-like outgrowth or corona at the mouth of the perianth-tube

Examine and sketch the perianths of the following flowers — Tulip, Hyacinth, Solomon's Seal, Snowdrop, Daffodil, Narcissus (several kinds, to show variation in form of corona, Fig 87), Early Purple Orchid, Bee Orchid, Twayblade Orchid, Lady's Slipper Orchid

335. Calyx.—The primitive, or simplest, type of calyx consists of spirally arranged *sepals*, which arise directly from the receptacle, as small green sessile leaves The individual sepals may be free (*polysepalous* calyx), or more or less united (*gamosepalous* calyx). However complete the union may be, the number of sepals which take part in the formation of the calyx is usually indicated by the pointed teeth borne on the upper margin of the tube

When a calyx is present, it is usually composed of two (Poppy), three (Lesser Celandine), four (Wallflower), or five (Buttercup) sepals More rarely the sepals are numerous, and retain their primitive spiral arrangement (Water-lilies, Cactuses)

The calyx commonly serves to protect the flower while it is still young, and hence, when the flower opens, the sepals either fall off (Poppy) or turn back (Dog Rose) Another of its functions, however, is to protect the developing fruit, and hence it often persists until the fruit is formed, as in the Bean, Strawberry, and Dead-nettle A gamosepalous calyx affords not only a more efficient protection to the flower-bud than a polysepalous one, but also gives support and protection to the base of the adult flower and to the developing fruit Hence the gamosepalous calyx never falls off when the flower is young In "Winter Cherry" the calyx forms a red bladder round the fruit

When the flowers and fruits are closely aggregated, they no longer need a protective calyx, which therefore becomes quite small, as in Umbellifers, and when a closely packed mass of flowers is surrounded by a ring of protective bracts, the calyx may either disappear (Daisy) or be represented only by hairs These hairs in the Dandelion, Thistle, Hawkweed, etc , persist after flowering, and form a *pappus*, which is attached to the ripened fruit and aids in its dispersal by the wind

The sepals are usually green, but the "petaloid" sepals of Monkshood, Winter Aconite, Christmas Rose, Larkspur, and Marsh Marigold are brightly coloured, and take on the attractive function of the petals, which are either developed as nectaries or are absent

Examine and sketch (1) the entire calyx, (2) the individual sepals, of the following flowers —Buttercup, Lesser Celandine, Wallflower, Sweet Pea, Gorse, Mallow, Rose, Cinquefoil, Strawberry, Cherry, Dead-Nettle, Foxglove, Larkspur, Monkshood, Christmas Rose, Winter Aconite

336 Corolla.—The primitive corolla consists of a spiral of free petals, but in most plants this has been changed into a single whorl (Foxglove, Geranium) or, more rarely, a double whorl of petals (Poppy) The corolla protects the stamens and carpels at the most critical period of their existence, and this is especially the case when the petals have grown together to form a tube enclosing the essential organs The corolla-tube often serves as a receptacle for honey, while the coloured portion attracts the visits of insects As soon as fertilisation has occurred, the seeds begin to develop, and an attractive corolla being no longer needed, it is usually rapidly shed The withered corolla may, however, persist round the fruit (*e.g* Heaths, Plantains, Clover).

When the corolla is polypetalous, the individual petals often consist of a narrow stalk or *claw*, and an upper broader portion, the blade or *limb* (Wallflower) The petals of the Pink have a scaly outgrowth (ligule) at the junction of the claw and limb, and in Narcissus there is a circular cup, or *corona*

The corolla is said to be *regular* when all its parts are similar, *irregular* when they differ in shape from one another, and the same terms apply whether it is poly- or gamopetalous In Christmas Rose and Winter Aconite the petals are represented by hollow nectaries, and the sepals form the showy attractive portion of the flower The nectaries are represented in the Buttercup by tiny pockets placed behind a scale at the base of the inner surface of each petal Hence the nectaries of the Christmas Rose are probably modified petals, as are undoubtedly the two posterior ones of the Monkshood

Examine and sketch (1) the entire corolla, (2) the individual petals if free, of the flowers mentioned in Art 335

337 The **Andrecium** is the collective term applied to the whole of the stamens present in any single flower Each stamen usually consists of two parts, a stalk or filament, and a head or anther There may be no filament, so that the anther is sessile, or the anther may not develope, when what remains is known as a *staminode* or sterile stamen The anther is usually divided into two halves or lobes, in each of which are two longitudinal compartments, filled, when ripe, with pollen grains When the anther splits open, or *dehisces*, the partition between the paired pollen sacs of each lobe breaks down to a greater or less extent, so that each lobe appears to have only a single cavity (Fig 88).

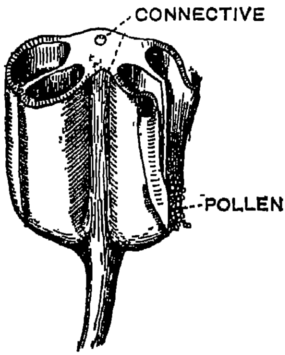

Fig 88 —An Anther with the top cut off.

The right anther lobe is represented as being dehisced

The prolongation of the filament between the two lobes of the anther is termed the *connective*. When the lobes are close together, this is narrow, but in Labiates and some other plants the connective is elongated laterally, and the anther lobes are widely separated Special appendages are occasionally developed from the connective ; each anther of the Violet has a membranous orange-coloured outgrowth at its apex, and in addition each of the two anterior stamens has an elongated process extending downwards into the spur of the anterior petal. The tip of this process is glandular, and secretes nectar into the spur.

As a general rule the different stamens of a flower are alike in shape, size, and in length of filament. Two of the stamens of the Wallflower, however, are shorter than the other four (*tetradynamous*), while the Dead-nettle has two long and two short stamens (*didynamous*).

The fully grown anther breaks open and allows the pollen to escape. It usually happens that the wall of each lobe splits longitudinally along the dividing line between its two compartments, but in many Labiates the anther opens transversely. In Potato, Rhododendron, Milkwort, etc., small pores are formed at the top of the anther. In the Barberry the whole side of each anther-lobe bends upwards; in the Laurel small doors or valves open at the sides of the anther.

Examine and sketch the stamens of the following flowers:—Buttercup, Gorse, Sweet Pea, Mallow, Potato, Violet, Pansy, Wallflower, Rhododendron, Heather, Dead-Nettle, Foxglove, Barberry, Bay Laurel, Fumitory or Dielytra ("Bleeding Heart"), Garden Sage.

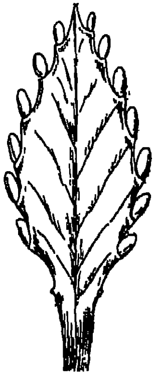

Fig 89.—Carpellary Leaf with Marginal Ovules.

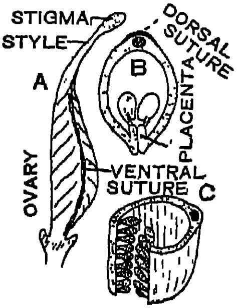

Fig 90.—The Monocarpellary Pistil (e g Bean, Pea).
A, Entire, B, Transverse section of Ovary, C, Will indicate method of folding.

338. The **Gyneocium** or **Pistil** is the collective term applied to the carpels present in a flower. In its simplest form the pistil consists of a single carpel, as in the Bean. Such a carpel corresponds to a leaf bearing ovules on its margins (Fig. 89), a condition in which the carpels of the Gymnospermous plant *Cycas* remain to the present day. We might suppose that as the higher flowering plants developed, the two halves of the carpellary leaf became folded longitudinally, and that their margins grew together along a line known as the ventral suture, which bears a double row of ovules derived from the two margins of the leaf

The purpose of this change is immediately obvious, for the young ovules are now protected within a hollow chamber known as the *ovary* (Fig 90), which is formed from the swollen basal portion of the carpel The apical portion of the latter forms a slender prolongation of greater or less length, the *style*, which usually contains a central canal communicating with the cavity of the ovary, but may be composed of loose, solid tissue with no definite central cavity The *stigma*, or apical portion of the style, is usually swollen and covered with hairs (stigmatic papillae) The stigma forms the receptive surface for the pollen The dorsal suture of the carpel corresponds to the midrib of a leaf; the cushion of tissue along the ventral suture, from which the ovules arise, is known as the *placenta* In the Water-lily, Flowering Rush, and a few other plants, the ovules are scattered all over the inner surface of the carpels

The flower of Buttercup or Rose contains several free simple carpels, and the pistil is therefore termed *apocarpous*. When several carpels are present in a flower, they are often united to form a compound or *syncarpous* pistil The union may be confined to the base of the ovary (some Saxifrages), or may include the entire ovary (Campion), or only the stigmas may be free (Foxglove), or all three may be completely united together (Primrose). A syncarpous ovary may be divided into a number of chambers, each corresponding to the cavity of one carpel Thus the Tulip has three carpels, and the ovary is divided into three chambers, each containing a double row of ovules.

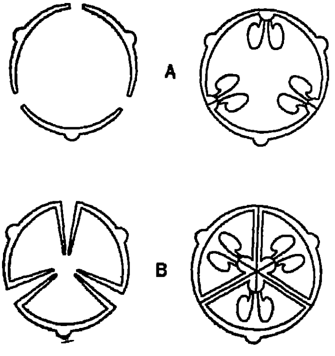

Fig. 91 —Diagram of Syncarpous Ovary, with Parietal (A) and Axile (B) Placentation

The ovary of the Violet has a single chamber only, although it is composed of three carpels, as is indicated by the presence of three groups of ovules arranged in longitudinal rows upon its wall. When, as in this case, the ovules are attached to the wall of a compound ovary, the placentation, or arrangement of the placentas, is said to be *parietal* (Fig. 91, A); but when the ovules arise from the longitudinal axis in the centre of the ovary, the placentation is said to be *axile* (Fig 91, B), *e.g* Bluebell, Tulip It will be noticed that when the placentation is axile, the ovules in each loculus are derived from the margins of the carpellary leaf that forms this chamber, whereas in the case of parietal placentation each group of ovules is derived from the margins of two adjacent carpellary leaves, half from each. In Chickweed, Stitchwort, Campions, Primrose, etc., the central axis of the ovary does not reach the roof of the latter, so that the ovules appear to arise from a mound in the centre of the ovary; this type of placentation is said to be *free-central*.

The number of chambers in an ovary usually corresponds, if there are more than one, to the number of carpels of which it is composed. In Labiates and Borages, however, each compartment of the bicarpellary gynecium is divided into two, so that there are four loculi, but only two carpels. The ripe ovary of the Flax becomes similarly divided into ten chambers instead of the five present at first.

Again, in unilocular ovaries with parietal placentation, each placenta usually corresponds to a single carpel. The number of styles or stigmas often corresponds to the number of component carpels, and the ripe fruit frequently splits into as many pieces as there are carpels.

In White Water-lily the numerous petals pass by gradual transitions into the more centrally placed stamens, all being spirally arranged on the receptacle; in double Roses the stamens, in double Buttercups both stamens and carpels, become petal-like, in White Clover the carpel sometimes remains open and produces green leaves on its edges, in Green Roses, double Cherry, etc., the carpels grow into green, white, or coloured leaves.

Examine and sketch (1) the entire pistil, (2) a cross-section of the ovary, (3) a longitudinal section of the ovary, of each of the following flowers:—Narcissus, Tulip, Buttercup, Marsh Marigold, Wallflower, Iris, Violet, Pansy, Mignonette, Dead-Nettle, Foxglove, Snapdragon, Cherry, Primrose, Stitchwort, Red Campion, Sweet William, Mallow.

339. Cohesion and Adhesion.—"Fusion" between the parts of the same or of different whorls is of common occurrence. When the parts of the same whorl are united, they are said to be *coherent*, but when union occurs between the parts of different whorls, the term *adherent* is employed.

Adhesion is not so common as cohesion, but in most flowers which have a corolla-tube or perianth-tube the filaments of the stamens are usually adherent to the tube, so that the stamens appear to arise from corolla or perianth instead of from the receptacle. Adhesion between stamens and pistil occurs in Orchids and a few other plants.

The apparent "fusion" of parts is really due to the formation of a ring-like upgrowth of the receptacle, carrying with it the free parts of the young flower, which thus appear to have a common base.

When the parts of the same whorl are **free**, the perianth is **polyphyllous**; the calyx **polysepalous**; the corolla **polypetalous**, the andrœcium **polyandrous**, the gynecium **apocarpous**.

By **cohesion** (union between *similar* floral parts) the perianth becomes **gamophyllous;** the calyx **gamosepalous,** the corolla **gamopetalous;** the andrœcium **monadelphous** (stamens united by filaments, *e.g.* Mallow, Gorse), **diadelphous** (nine stamens united by filaments, one free, in most Papilionaceæ), **polyadelphous** (stamens united by filaments into several bundles, *e.g.* St John's Wort), or **syngenesious** (stamens united by their anthers, *e.g.* Compositæ), the gynecium **syncarpous,** the styles and stigmas sometimes remaining free.

Adhesion (union between *dissimilar* parts) occurs only between the *stamens* and other parts; the stamens are **epiphyllous** when united by their filaments to the perianth; **epipetalous** when so united to the corolla; **gynandrous** when united to the style (Orchids).

340. Symmetry of the Flower.—Nearly all flowers are symmetrical, *i.e.* can be divided into two corresponding halves. When it can be so divided along one plane only it is said to be bilaterally symmetrical or *zygomorphic*, but when the flower may be equally divided in several planes it is radially symmetrical or *actinomorphic*. In regarding flowers from the biological point of view, we may restrict these terms to the perianth. A flower that can be visited from any side has a radially symmetrical ("regular") mechanism, whereas that of a flower which can be properly visited from one side only is zygomorphic ("irregular").

341. The Floral Diagram.—The general structure of a flower and the arrangement of its parts may be graphically represented by means of drawings of vertical and horizontal sections. The latter are always drawn as a ground-plan showing all the parts in the same figure, and the term "floral diagram" is applied to them.

It is always of great importance in such diagrams to correctly represent the position of the flower with regard to the stem and bract connected with it. The face of the flower turned towards the stem is called the posterior face, that towards the bract is the anterior one. Cohesion of parts may be indicated by connecting lines. Difficulty is often experienced in correctly orienting the flower with regard to the stem, and it is useful to remember that there is a single posterior sepal in most Dicotyledons, if we except the Leguminosae and also a few plants in which the posterior sepal has not developed. The parts of the typical Monocotyledonous flower are arranged in regular cycles of three, and the odd sepal is usually anterior.

Make the diagram of good size (at least 2 ins in diameter). To get a transverse section of a small ovary, do not remove the sepals, etc., but cut right across the flower, holding the flower upside down, and cutting thin slices with a razor or sharp knife (beginning at the base of the flower) until the interior of the ovary is exposed. To cut a flower longitudinally through the middle, it is usually best to begin the cut at the base of the flower.

342. The Floral Formula.—As a means of readily and rapidly indicating the essential features in the structure of a flower, what are known as floral formulae are frequently employed, and these, together with the diagram and vertical (longitudinal) section (with the parts labelled), will represent all the essential features in the structure of the flower without a word of description being necessary.

The symbols ⊕ and † respectively denote radially and bilaterally symmetrical (zygomorphic) flowers. The signs ♂, ♀, ☿ respectively denote staminate, carpellary, and hermaphrodite ("perfect") flowers. The letters K, C, or P represent the calyx and corolla (or perianth), A and G the andrecium (stamens) and gynecium (pistil), and the figure following each letter gives the number of parts in each series. Cohesion is indicated by brackets enclosing the number of parts, a horizontal bracket ⌒ indicates adhesion between the parts of successive whorls, a horizontal line above G means that the ovary is inferior, a line below G that it is superior; the symbol ∞ is used when there are numerous parts in any series. The following floral formulas will serve as illustrations:—

Buttercup . .	$\oplus K5,\ C5,\ A\infty,\ G\underline{\infty}$
Narcissus . ..	$\oplus P\overparen{(3+3),A}3+3,\ G\ \overline{(3)}$
Violet	$\dagger K5,\ C5,\ A5,\ G\ \underline{(3).}$
Dead-Nettle .	$\dagger K(5),\ \overparen{C(5),\ A}2+2,\ G\ \underline{(2).}$
Stitchwort	$\oplus K5,\ C5,\ A5+5,\ G\ \underline{(3)}$

Draw the floral diagram and write the floral formula of the following flowers Lesser Celandine, Marsh Marigold, Larkspur, Broad Bean, Gorse, Tulip, Iris, Early Purple Orchid, White Dead-Nettle, Foxglove, Sweet William, Primrose, Wallflower

343. Perigyny and Epigyny.—The shape of the receptacle or thalamus varies very much in different flowers The receptacle of the Buttercup is convex, and the successive cycles of floral parts are placed upon it, one above the other, the sepals arising first and the carpels last Flowers of this type are said to be **hypogynous**, and the pistil *superior*

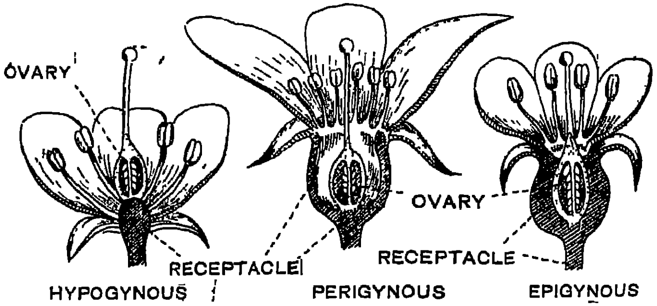

Fig 92.—Vertical Sections of Flowers, showing different forms of the Receptacle

(Fig. 92) In such flowers the young and succulent ovaries are exposed to various climatic influences, including strong winds, intense sunlight, and rapid changes of temperature, any of which may act injuriously upon the development of the ovules, if the carpels are thin and freely exposed. There is a tendency in most Flowering Plants to protect the ovary from the influences mentioned above, and this tendency finds expression in three distinct ways

(1) The petals tend to unite, as also do the sepals, thus producing flowers of very specialised character (generally in connexion with insect-pollination), in which the ovary is, at the same time, protected to a certain extent from injurious external influences

(2) The receptacle becomes more or less concave, and so encloses and protects the carpel or carpels, leaving the stigma

exposed at the end of the style (*e g* Cherry, Rose) Such flowers are said to be **perigynous**, but in many cases only the marginal portion of the receptacle is concave or flattened, so that the sepals and petals seem to have a common origin, while the carpels arise from a prominence in the centre of the flower (*e g* Blackberry) In perigynous flowers the pistil is attached to the receptacle by its base only, and it is still said to be superior even when the entire receptacle is concave and only the stigmas project above it

(3) The receptacle grows around the ovary so that the latter becomes completely embedded in it, the style and stigma remaining free Here the ovary is said to be *inferior* and the flower *perigynous* The ovary is thus protected, and an increased surface is offered for the passage of food to the developing ovules from the receptacle

Make and sketch longitudinal sections of the following flowers · Buttercup, Narcissus, Tulip, Monkshood, Larkspur, Dead-Nettle, Foxglove, Snapdragon, Early Purple Orchid, Violet, Pansy, Primrose, Sweet Pea, Canterbury Bell, Rose, Cherry, Bramble, Apple Determine whether the flower is hypogynous, perigynous, or epigynous In each case draw the floral diagram and write the floral formula

344. Nectaries.—The receptacle frequently bears a fleshy or glandular outgrowth, such as is found on the top of the inferior ovary in Umbelliferae and in the common Ivy. This is termed the disc. In the Blackberry the disc lines the outer concave part of the receptacle Very commonly the disc is lobed (Vine, Wallflower), and frequently it secretes nectar Nectaries may, however, develop from, or upon, any part of the flower. Thus in the Violet the appendages borne by two of the stamens secrete nectar into the hollow spur of the anterior petal In the Buttercup the small kidney-shaped projection at the base of each of the petals covers a small gland, while the petals of the Christmas Rose are represented by hollow tubular nectaries. Honey glands occur upon the pistil of Gentians, and each sepal of the Hollyhock flower bears a nectary on its inner surface.

Examine and sketch the nectaries of the following flowers. Buttercup, Lesser Celandine, Christmas Rose, Winter Aconite, Monkshood, Larkspur, Violet, Pansy, Dead-Nettle, Snapdragon.

345. Inflorescences.—Flowers may either be solitary or may occur in clusters In the latter case they are usually subtended by special leaves termed bracts Solitary flowers may be either terminal, as in Tulip and Daffodil, or may arise in the axils of ordinary leaves, as in Pimpernel

The branching of an inflorescence may be either cymose or racemose. In racemose inflorescences the main axis is stouter and longer than the lateral ones, whereas in the cymose type the lateral axes branch more than does the main axis beyond them The growth of the main axis is in this case strictly limited, and it bears usually one or two lateral axes, instead of the numerous axes which characterise most racemes

The order of flowering usually follows the order of development, and hence the flowering in racemes is generally centripetal, whereas that of cymes is on the whole centrifugal That is, in the first case the youngest flowers are nearest the apex (in a long inflorescence) or the centre (in a flat- or round-topped inflorescence), while in the second case the youngest flowers are nearest the base or the outside of the inflorescence

The simplest type of **raceme** consists of an elongated axis or peduncle which bears stalked flowers (stalks about equal in length), e g Foxglove, Hyacinth If the branches of the parent axis branch again so that each secondary axis bears several blossoms instead of one, we have what is known as the compound raceme or **panicle.** This is the most primitive type of inflorescence, for it is really the modified upper region of the plant, whereas the simple raceme is more highly differentiated and has become simple by reduction Many terms have been applied to racemose inflorescences which look peculiar at first sight, but on further observation are seen to differ in small details only The more important of these are—(1) **Corymb:** axis elongated, flower-stalks unequal in length, bringing the flowers to about the same level (Fig 93), (2) **Spike:** axis elongated, flowers sessile (Plantain, Orchids), (3) **Catkin:** a spike bearing unisexual flowers of one kind

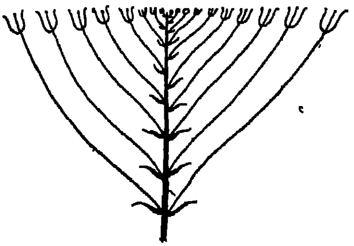

Fig 93 —A Corymb

(Willow, Hazel); (4) **Spadix**: a spike with fleshy axis, usually bearing unisexual flowers, enclosed by a large bract, the **spathe** (Arum), (5) **Simple umbel**: axis shortened, flowers stalked (Fig 94); (6) **Capitulum**: axis shortened and expanded, flowers sessile (Composites)

Cymose inflorescences are those in which the axis ends in a flower after bearing one, two, or more daughter-axes, each of which may repeat the process The daughter-axes may come off singly (**uniparous cyme**)—*e.g* Forget-me-not and other Borages, Sundew, or in opposite pairs (**biparous cyme**)—*e g* Stitchwort and Campion Family, Red and Yellow Gentians, or in whorls of three or more (**multiparous cyme**)—*e g* Elder

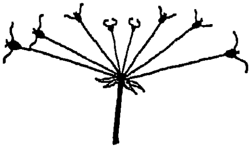

Fig 94 —A Simple Umbel

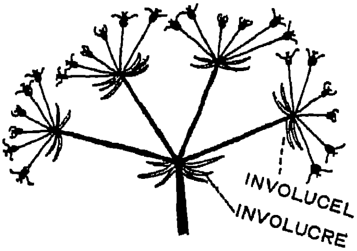

Fig 95 —A Compound Umbel

Examine and sketch the various kinds of **flat-topped inflorescences** met with, noting that plants with inflorescences of this kind are found in many different Orders—*e g* Cruciferae (Candytuft, etc), Rosaceae (Cherry, Rowan, Meadowsweet, Hawthorn, etc), Leguminosae (Clovers, *Lotus*, etc), Umbellifers, Ivy, Dogwood, Elder, Valerians, Dipsaceae, Sheep's-bit, Compositae, etc

It seems probable that all cymose inflorescences have been derived from racemose ones by a shortening of the main axis and a delay in the development of the lateral branches, to which the main power of growth is at the same time transferred The cymose inflorescence is certainly an advance upon the racemose type, for in the former new flowers continually appear on the exposed surface of the inflorescence, while the fruits ripen securely buried among the older parts of the mass of branches. The tendency in racemes, on the other hand, is to simultaneous flowering, such as is exhibited more or less perfectly by so many umbels and capitula and especially by corymbs In such cases there is an ever-present danger that the short period of flowering may occur at a time when the conditions are not suitable for the production of fertile seed

Racemes such as those of the Wallflower, in which the lower flowers may open months before the apex of the raceme ceases flowering, do not incur this danger, but the exposed position of the young succulent fruits is an obvious disadvantage here and in other Crucifers also If the growing point of a young raceme is destroyed, the power of producing flowers may be temporarily lost, whereas the destruction of the apex of a cyme involves the loss of a single flower only, and the lateral axes continue their growth with even greater vigour than before

Compound inflorescences are those in which the lateral branches are again branched in the same way as the parent axis The commonest kinds are (1) **Panicle** (raceme of racemes or spikes), common in Grasses; (2) **Compound spike** (a spike of spikes), in some Grasses, *e.g* Wheat; (3) **Compound umbel,** much commoner than the simple umbel (most Umbelliferae, Fig 95)

In many cases **mixed inflorescences** occur—as, for example, racemes of spikes, capitulums, or cymes, spikes of capitulums, etc It must, however, be borne in mind that there are only three main types of inflorescence, and these are (1) the raceme, with its reduction derivatives grouped around the generalised panicle type, (2) the biparous cyme; (3) the uniparous cyme "Mixed" inflorescences arise owing to the fact that reduction or alteration has unequally affected the different parts of the primitive panicled inflorescence. The inflorescence of the garden Geranium (*Pelargonium*) and of many Narcissi resembles an umbel, but the flowers in the apparent umbel are really arranged in little cymose clusters, so that the whole inflorescence has been termed an umbellate cymose head

The apparent flowers of the Spurge (*Euphorbia*) are really inflorescences, which are sometimes termed cyathiums (Fig 96) Each is surrounded by a cup-shaped involucre formed by the union of five bracts Four crescentic glandular scales occur at the margin of the involucre between four of the bracts Inside the cup there appear to be a number of stamens and a single ovary borne on a stalk The latter is really a carpellary flower, and each of the former corresponds to a single staminate flower, as is indicated by the fact that each stamen is articulated to a short stalk, and that at this point a small scaly bract occurs In some allied plants a small perianth is present at the base of every stamen, which clearly shows that each of them corresponds to a single reduced flower.

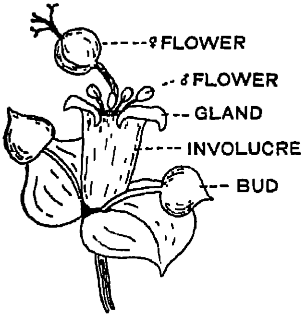

Fig 96 —Inflorescence of Euphorbia.

The occurrence of bracts, and the positions which they occupy, are features of great importance in determining the nature of compound or mixed inflorescences Bracts are usually green, and smaller and simpler than the foliage-leaves. In some Sages they are brightly coloured, and take on the attractive function of a corolla They are absent from most Cruciferae and Papilionaceae, and the flowers (florets) of most Umbelliferae and Compositae are bractless. Sometimes a series of specially modified leaves which do not subtend flowers, and which therefore are, strictly speaking, not bracts at all, are grouped around the inflorescence. Thus the end of the Daisy or Dandelion has a ring or *involucre* of green "bracts" around it, although the individual flowers have none. In the head of the Sunflower, however, each flower arises in the axil of a true scaly bract. Sometimes, as in Narcissus, Arums, and Palms, the entire inflorescence is enclosed when young by a single large "bract" or spathe. The latter, however, is simply the uppermost leaf on the stem, and it is not a true bract at all, for the inflorescence is terminal and not axillary.

The student will usually have little trouble in making out the nature of any inflorescence if the foregoing paragraphs have been mastered. Specimens of all the plants mentioned should be examined carefully.

Examine the inflorescences of Buttercup (cymose), Foxglove, Bluebell, Wallflower, Candytuft, Cherry, Cowslip, Ivy, Cow Parsnip, Pelargonium, Stitchwort, Chickweed, Sweet William, Elder, Willow, Plantain, Sunflower, Daisy, Spurge.

346. Contrivances and Conditions favouring Cross-Pollination.—There are in flowers many forms, conditions, and mechanisms, the significance of which becomes clear only on the view that cross-fertilisation is advantageous, and that the flowers have become adapted to it. Such mechanisms, etc., either entirely prevent self-pollination, or tend to do so, and are distinct adaptations for cross-pollination.

To commence with, in many plants cross-pollination is absolutely necessary if seed is to be produced, owing to the flowers being unisexual. We have this condition in its extreme form where the staminate and pistillate flowers are on different plants (*e.g.* Willow). Some plants are self-sterile, *i.e.* the flower cannot be fertilised by its own pollen; this occurs in some species of Passion-flower, of Lobelia, of Abutilon, etc.

Dichogamy is a condition in which, though the flowers are hermaphrodite, the anthers and stigmas come to maturity at different times, and which, when completely developed, entirely prevents self-pollination. There are two kinds of dichogamy: (*a*) **protandry**, where the anthers ripen first: here the pollen grains are transferred to an older flower; (*b*) **protogyny**, where the stigma ripens first: here the pollen grains are transferred to a younger flower. Protandrous flowers are much more common than protogynous. Examples of the former are found in Composites, Labiates, Harebells, Ivy, Umbellifers, Willow-herbs, etc., of the latter in Plantains, Woodrush, Figwort, Hawthorn, Christmas Rose, etc. Wind-pollinated flowers are more often protogynous than protandrous, but many are unisexual.

Wind-pollinated and insect-pollinated flowers have each special characters of their own, so that as a rule we can distinguish them at a glance In wind-pollinated flowers the pollen is produced in great abundance, as much of it must be wasted, the flowers are small and inconspicuous; there is no honey or perfume, and frequently the stigmas are branched and feathery, to catch the pollen grains

The greatest variety, however, is shown in insect-pollinated flowers, there is no difficulty in recognising these as being the most highly specialised As a rule they have large, conspicuous, brightly coloured corollas, or are arranged in conspicuous inflorescences, they usually secrete honey and give out perfume Pollen is not usually produced in great abundance, as the provision for its transference is more perfect The bright corollas, the perfume and honey, serve to attract insects In return for the service rendered by insects the flowers sacrifice part of their nutritive substance in providing food to the insects (honey and pollen), and make a further sacrifice of energy in developing certain structures (corollas) which will attract the insects

A honeyless but otherwise insect-attracting flower is sometimes called a "pollen-flower," examples being seen in Poppies, Dog Rose, Rock-rose (not a true Rose), Wood Anemone, Traveller's Joy, St John's Wort, Gorse, Broom, Meadow-sweet

In many cases the corolla is so modified that the insect must alight on the flower or enter it in a special way (*e g.* Labiates, Papilionaceae), the same result may be attained by the secretion of nectar into special receptacles or spurs (*e g.* Violet), or the insect, on entering a flower, pushes against special processes or outgrowths which move the stamens and bring the anthers in contact with its body (Sage); or the stamens may be jerked, and the pollen scattered over the insect's body (Barberry, Kalmia).

The general result of all these devices is that the insect receives the pollen on a special part of its body, and when it enters another flower the pollen is deposited on the stigma.

If the flower-stalk were *erect*, not only would rain get in and spoil the pollen and honey, but the pollen would not fall into the "pollen-box." If the pollen were sticky, the grains would cling to the anthers and would not be touched by the bee.

The flowers are *homogamous*, since the style-tip is ready to receive pollen at the time the anthers open, but self-pollination is hindered by the projection of the style beyond the "pollen-box."

In Violets the anthers simply touch each other, edge to edge, so that some pollen may escape between them, but most of the pollen can only escape through the small circular slit between the style and the tips of the anther scales. In Pansies the anthers are firmly joined by the hairs on their edges, and the pollen escapes by an opening between the scales of the two lowest anthers, but this opening is separated from the stigmatic opening above it by the stigma-lip ("scraper").

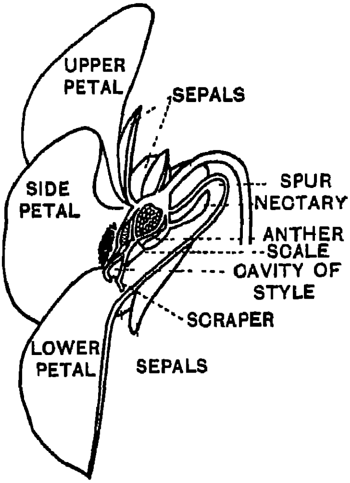

Fig 99 —Longitudinal Section of Flower of Garden Pansy

In most *Viola* species plants protected against insects seldom fruit, but there is nothing which absolutely prevents self-pollination by insects visiting the flower in the proper way. The entrance of undesirable insects—small insects which would not be likely to effect cross-pollination—is hindered by the hairs on the side-petals and (in Pansies) on the sides of the stigma; the opening of the spur is further protected by the overhanging style-beak or the "scraper," the narrow groove on the spur-petal, the hairs lining the entrance and cavity of the spur (which species show one or more of these features most markedly?), and, of course, the length of the spur itself. On the other hand, the visits of long-tongued insects are encouraged by the conspicuous orange-coloured centre of the flower, heightened by the dark streaks ("honey-guides") which stand out vividly from the otherwise light-coloured bases of the spur-petals and side-petals (especially in Pansies) and which (since they follow the *veins*) converge to the spur-opening.

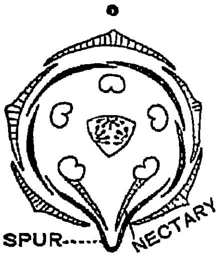

Fig. 100 —Floral Diagram of Violet

(*f*) Examine the yellow flowers of **Barberry**, noting the arrangement of the flower-parts in threes What peculiarity is shown by the stamens? Push a pointed pencil or match-stick into the flower, imitating the action of a bee or wasp probing for the honey at the bases of the stamens, and notice what happens

347. Special Arrangements for Self-Pollination.—Many annual plants cannot afford to undertake the risks and sacrifices attendant on cross-pollination, and are commonly self-pollinated (*e g* Groundsel, Chickweed). They have small flowers, often without honey or smell, and are either **homogamous**—that is, their anthers and stigmas mature at the same time—or so slightly dichogamous that self-pollination is secure Even in flowers evidently adapted for cross-pollination there is commonly the possibility of self-pollination as a last resort Many of them are distinctly dichogamous, but not completely so, there being usually a short period during which self-pollination becomes possible To effect this there are sometimes special contrivances, such as the curling back of the stigmas to reach the pollen (*e g* Nigella, Composites, Campanulaceae)

A very special adaptation for self-pollination is the production of **cleistogamic flowers.** These are closed flowers produced late in the year by certain plants which had previously produced ordinary flowers—*e g* Sweet Violet, Wood Sorrel, Henbit Dead-nettle (*Lamium amplexicaule*) The cleistogamic flower is small and inconspicuous, the calyx never opens, and the stamens and pistil are developed in a closed case

In our study of flower-mechanisms we are too apt to forget that self-pollination occurs regularly in most flowers where it is not precluded by dioecism, complete dichogamy, or self-sterility, that it is rarely *much* inferior to cross-pollination in its results, and that it is always better than *no* pollination.

In Violets the flowering-period of the ordinary insect-pollinated flowers is short (rarely more than six weeks) and the number of flowers produced is small—especially in Sweet Violets, in which flowering only lasts for a month and a plant produces only about six flowers, each flower lasting about a week in a condition ready for pollination. Except in very bad weather these spring flowers are visited and pollinated by bees, but flowering does not stop when no more of the ordinary flowers are to be seen. The plant goes on producing flower-buds until autumn Those which succeed the early (normal) flowers do not open but are self-pollinated, so that fruits are continually formed during summer Finally in autumn a few buds are laid down for the normal insect-pollinated flowers which will open next spring

In Sweet Violet these closed self-pollinating (*cleistogamic*) flowers have five very small petals and five stamens, but in Dog Violet there are only two stamens (the lowest ones) The anthers produce few pollen-grains (why few?) and do not open, the grains sprout inside the anther, and the pollen-tubes grow through the anther-wall and the style to reach the ovules. The formation of these flowers is partly dependent on shade, they are always shaded by the leaves of the plant itself If a plant is kept in feeble light, it will usually produce only these cleistogamic flowers

Like Violets, Wood Sorrel relies largely upon small and inconspicuous cleistogamic flowers for its propagation. In these flowers, produced in late summer or in autumn, the number of pollen-grains developed in the anthers is remarkably small (about a dozen in the smaller anthers, two dozen in the larger ones), but the capsules produced are much larger than those arising from the ordinary open flowers The fruits produced by the cleistogamic flowers are thrust downwards into the soil, or at any rate brought close to it, by the downward curvature of the flower-stalk The fruits produced by the ordinary flowers, however, show a remarkable mechanism for the scattering of the seeds (Art 378).

348. Insects that visit Flowers.—The chief flower-visiting insects are beetles (Coleoptera), flies (Diptera), bees and wasps (Hymenoptera), butterflies and moths (Lepidoptera) For our purposes, the chief differences between these insects are the size of the body, the length of the tongue (proboscis), the time of year at which each kind is most plentiful, and their habits—*e.g* whether they collect pollen or honey or both, whether they fly by day or in the evening

By carefully studying the structure of a flower, and noting such points as the time of flowering, the order in which the anthers and stigmas mature, the relative positions of anthers and stigmas in the open flower and any changes in position that may occur, we can often tell what kind of insect is capable of effecting cross-pollination, and whether or not self-pollination is possible. We shall deal later with the characters of flowers which are mainly or entirely pollinated by the wind, and which lack the conspicuous colouring, scent, and nectar characteristic of insect-pollinated flowers (though not necessarily *all* present in the same flower).

There is only one way in which to study this fascinating subject—by going out and patiently watching the various insects which visit flowers. If you can get to know the names of the insects, do so; in any case it is usually easy to tell whether it is a butterfly or moth (four wings covered with scales, proboscis often long and coiled up, feelers or antennae with club-like ends in most butterflies, tapering and feathery in most moths), a bee or wasp (wings membranous, body usually banded with yellow and black, ovipositor at hinder end of female's body, used also as a sting), a fly (two clear wings with no scales or hairs and few veins—mostly longitudinal), or a beetle (front wings form two hard cases—elytra—covering the two soft hinder flying-wings, mouth-parts adapted for biting only). However, there are many books on insect-study (Entomology), some of which should be consulted; note especially the size of the insects, their habits and mode of life, and their mouth-parts (whether biting or sucking, etc.).

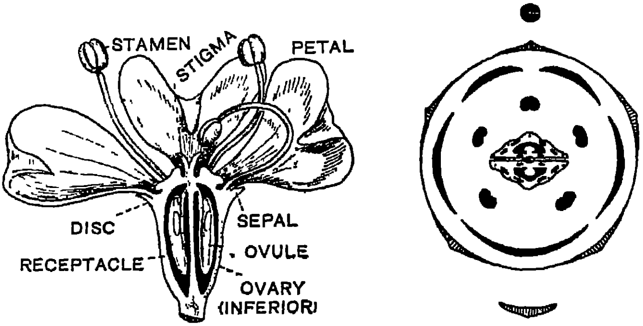

Fig. 101.—Vertical Section and Floral Diagram of Flower of Cow Parsnip.

It is interesting, if a microscope is available, to examine pollen-grains of known flowers, sketch them, and keep preparations (mounted in glycerine jelly) for reference, and then to catch insects and examine any pollen-grains that may be on their bodies.

349. Flowers adapted for Short-tongued Insects.—Most flies and beetles have very short tongues, usually less than 3 mm long (about one-eighth inch), and are only able to lick honey which is freely exposed on the surface, as in Ivy, Umbellifers (Fig. 101), Dogwood (Cornus), Bedstraw, Goosegrass, Golden Saxifrage (Fig. 102, B), or in flowers with a very short tube, *e.g.* Moschatel, Enchanter's Nightshade (Fig. 103), or in various shallow open flowers, *e.g.* Saxifrages (Fig. 102, A), Stonecrop. They can of course visit any shallow flowers, and at least get pollen from honeyless "pollen-flowers," *e.g.* Wood Anemone, Clematis, Poppy, Dog Rose, Rock Rose, St. John's Wort. Some flowers show remarkable adaptations for pollination by flies, which are, as a rule, much lower in intelligence than the other classes of flower-visiting insects.

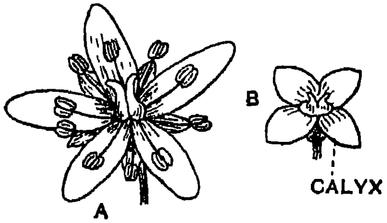

Fig. 102.—A, Flower of a Saxifrage; B, Flower of *Chrysosplenium* (Golden Saxifrage)

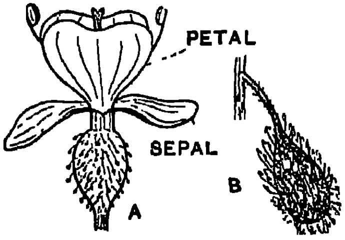

Fig. 103.—A, Flower; B, Fruit of Enchanter's Nightshade

One of the commonest beetles seen visiting flowers is a small bronze-black one called *Meligethes*, but very few beetles have tongues over 3 mm. Most of the larger and longer-tongued flies (*e.g.* the Tabanids—Gad-flies, "Cleggs," Horse-flies) do not visit flowers, those just mentioned being blood-suckers, but some (with tongues sometimes as long as 12 mm.) are regular flower-visitors. These belong chiefly to two families—Hover-flies (Syrphids) and Bee-flies (Bombylids). The former (*Eristalis*, *Syrphus*, *Rhingia*, etc.) often resemble bees and wasps in having a banded body, and many flowers are adapted for their visits, *e.g.* Speedwell, in which the two stamens form an alighting-place for the fly. The Bombylids also visit flowers, and some are nearly as clever as the bees they resemble at finding concealed honey with their long tongues; of the few British forms, *Bombylius* (hairy body, humped thorax, slender legs) is of great importance in the pollination of spring flowers, *e.g.* Primrose.

Among the smaller flies (tongues less than 3 mm. long) several visit flowers, e.g. *Lucilia* (small blue-bottle), *Anthomyia*, Dung flies, Midges, Thrips; some of these feed on decaying matter, and some flowers appear to be specially adapted for their visits, having a peculiar odour, e.g. *Arum*, Hawthorn, Moschatel, Rowan.

(*a*) Examine the compound umbels of **Cow Parsnip**, a tall umbellifer common in hedgerows and beside ditches. The compound umbel (Fig. 95) is derived from a simple umbel (Fig. 94) by each branch producing an umbel of flowers instead of a single flower. The result is a conspicuous massing of the individually small flowers; the flowers all open almost at the same time, and the outer ones have irregular corollas (as in a corymb). Why is it better for the plant to produce numerous small flowers and mass them together in this way than to produce a few large flowers?

Note the five free petals (how do those of the outer flowers differ from those of the central ones?); the sepals are small or absent (how, then, are the flower-buds protected?); the five stamens alternating with the petals; the honey-disc round the two short stigmas at the top of the flower; the flattened inferior ovary (Fig. 101).

The honey is freely exposed, so that insects with short tongues can lick it, and the flowers are largely visited by flies and beetles. Cow Parsnip, like most other Umbellifers, shows extreme protandry; as a rule the stamens of every flower in a whole umbel have shed their pollen and withered before any of the stigmas expand to receive pollen. In this way self-pollination is prevented.

(*b*) Examine the peculiar "flowers" of the **Cuckoo-pint** (*Arum*), so common in our hedgerows, where it blooms in April and May (Fig. 104). The whole "flower" is enclosed in a large green and purple leaf (the *spathe*). The upper portion of the spathe opens, exposing the bright purple club-shaped upper part of the spadix, while the lower bulbous portion remains closed except at the top, where it contracts to form a narrow throat. Cut open the lower part, and you see that the spadix is continued downwards, forming an axis, round which are situated two clusters of small flowers. The upper cluster is a dense mass of male flowers, each consisting of a single stamen; and the lower is a similar mass of female flowers, each consisting of a single carpel. Above each cluster are some abortive flowers that are reduced to hair-like structures, those above the stamens being longer, directed downwards, and lying in the contracted portion of the spathe.

If the flower under examination has recently opened, we find that the female flowers only are mature, but if it is one that has been open for some time, the female flowers are beginning to develop into fruits, and at the same time secrete a sweet fluid, while the male flowers are shedding their pollen. Thus the female flowers are not pollinated by the agency of the male flowers above them, how then are they pollinated?

On opening the lower part of the spathe we always find within it a number of little flies ("midges") which have been assisted in finding their present abode by the conspicuous nature of the spathe and spadix. All these flies are more or less dusted with pollen collected either here or from flowers previously visited. When the flies visit an Arum during its first or female stage, they find no food, and crawl about in their attempts to escape, but they are securely entrapped by the hairs at the neck of the spathe, which hairs, pointing downwards, allow easy access to the interior, but effectually prevent escape. However, in their movements the flies rub their bodies over the sticky stigmas, which are thus pollinated by the grains previously obtained in other Arums.

The fertilised ovaries now begin to develop into fruits, while the anthers open, shedding abundance of pollen-grains that cover the bodies of the imprisoned flies. Then the hairs wither, setting free the flies after the work of pollination has been effected, and after they have become covered with pollen to prepare them for a repetition of the process in other flowers visited.

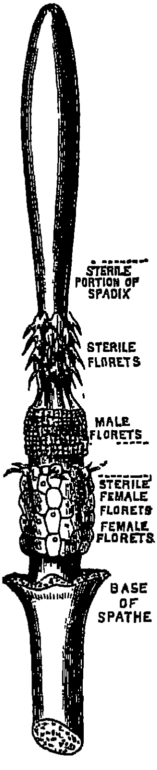

Fig 104.—Spadix of Arum

Spathe removed to show the Flowers.

350. Flowers with partially Concealed Honey.—Many flowers have arrangements for concealing the honey from the shortest-tongued insects, so that the visiting insects must have tongues at least about 4 mm. in length to reach it. The honey may be slightly concealed by the stamens—*e.g.* Buttercup, Stitchwort; by the erect, stiff sepals in the smaller Crucifers; by the formation of a shallow receptacle-cup in many Rosaceae—*e g* Strawberry, Cinquefoil; or by a short corolla-tube—*e g* the shorter-tubed Composites and Labiates, Valerians, Viburnum, Guelder Rose, Speedwell Such flowers are visited by the longer-tongued beetles and flies, as well as by insects of higher type

351. Flowers with fully Concealed Honey.—This type of flower differs only in degree from the last Here the honey is out of the reach of the short-tongued insects, and can only be obtained by those having tongues about 6 mm long, including the longest-tongued flies (chiefly the Hover-flies and Bee-flies) and the shorter-tongued bees—*e g* burrowing bees (*Andrena*, tongue 2 or 3 mm), hive-bees (*Apis*, tongue 5 or 6 mm)—and wasps

The concealment of the honey is effected by a further deepening of the flower, due to formation of a receptacle-tube, or to the sepals or petals (or both) growing out vertically from the receptacle (instead of spreading as in shallow flowers), and in many cases being joined below to a tube—*i e.* being gamosepalous or gamopetalous.

Examples of medium-tubed flowers are seen in Blackberry, Currants, Gooseberry, Pasque Flower, Willow-herb, Geranium, Mint (compare these to see how the tube is formed in each case, and try to find other examples) Some flowers seem to be chiefly visited by wasps, *e.g* Figwort (*Scrophularia*), Snowberry, *Epipactis*, Cotoneaster

Some of the most interesting flowers belong to this type and the next, including the characteristic "bee-flowers," *i e* flowers adapted to, and extensively visited by, bees.

352. Long-tubed Flowers.—When the flower-tube becomes longer, all these shorter-tongued insects are more or less completely excluded, and the flower is adapted for, and chiefly visited by, the larger bees (especially the humble-bees), butterflies, and moths Many flowers belonging to the Lily, Daffodil, and Iris families of Monocotyledons come under this type In most long-tubed flowers the honey is found only in the lower part of the tube, but in Crocus it fills the space between the style and the long flower-tube, and is therefore easily reached by bees and butterflies

Flowers like those of Papilionaceae, Snapdragon, and Toadflax can only be opened by large bees, and only the longest-tongued bees can reach the honey in such flowers as Monkshood and Larkspur. The humble-bees have longer tongues (about 10 mm in *Bombus terrestris*, 20 mm in *B hortorum* and in *Anthophora*) than hive-bees. Moreover, the humble- and hive-bees have the most perfect mechanism (the "pollen-baskets" on the hind-legs) for collecting pollen to mix with honey and feed their brood. Humble-bees are particularly skilful in finding the way to well-concealed honey. In this connection compare Red Clover and White Dead-nettle (humble-bees) with White Clover and Red Dead-nettle (smaller bees).

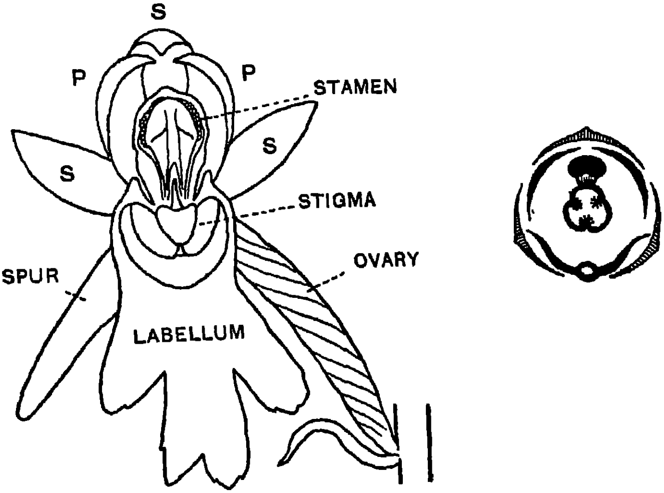

Fig 105 —Flower (front view) and Floral Diagram of Orchis.

Blue, purple, and red colours are often associated with flowers visited by bees (especially blue and purple) and butterflies (especially red), while flowers visited by other insects are usually white, yellow, or variegated, but there are far too many exceptions to allow of a general rule.

Some of the chief points in the wonderful mechanism of Orchid flowers can be made out in the Early Purple Orchid (*Orchis mascula*), which sends up in April a rosette of strap-shaped leaves surrounding the inflorescence The latter is a raceme, but the stalks of the flowers are very short, the long inferior ovary makes a long flower-stalk unnecessary, as it pushes out the flower and exposes it to visiting insects

Note the three sepals, alike in form and size, the three petals, one of which is larger than and different in shape from the other two This large petal (*labellum*) consists of a broad lip and a curved spur; it is really the uppermost petal, but has been brought round to the front of the flower by the twisting of the ovary, as can easily be made out

There is but one stamen, which is carried up with the style so as to stand above the stigma, and it consists of two club-shaped bodies, the pollinia. Each pollinium is enclosed in a sheath which opens by a slit on each side, and the stalks of the two pollinia are joined below to a sticky disc The pollinia represent an anther, each lobe consisting of pollen-grains massed together into packets joined by elastic threads

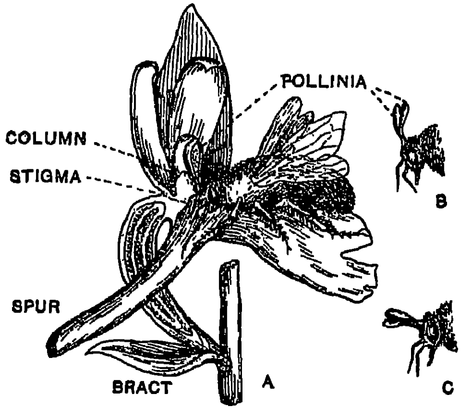

Fig 100.—Pollination of Orchid by a Bee

At C the pollinia have bent forward and will touch the stigma of the next flower visited.

A bee visiting the flower pushes its head against the disc as it pokes its tongue into the spur, and when it leaves the flower it carries off the pollinia, planted on its head The disc then contracts, bending downwards and forwards as it dries, so that the thick end of a pollinium will touch the sticky stigma of the next flower visited and some of the pollen will be dragged off

The pollinia remain fixed on the bee's head, because the sticky disc soon hardens, so that a single pair of pollinia may be carried about for a long time and pollinate several flowers before all the pollen is pulled off by the stigmas One often sees a bee, which has been visiting orchids, carrying a dozen pollinia stuck on its head and thorax Push a pointed pencil into the spur of the labellum (to imitate the action of a bee thrusting in its tongue to scrape the honeyed walls of the spur) Notice the two club-shaped masses of pollen which are withdrawn from their pockets and remain attached to the pencil by the sticky mass at the base of their stalks What change in position do the pollinia undergo after being removed, and how does this help in bringing about cross-pollination?

353. Butterfly- and Moth-Flowers.—When the flower-tube (or at any rate the level of the honey) is more than about 12 mm (about half an inch) deep, the honey is beyond the reach of bees, though they may visit the flower for pollen or the humble-bee may bite through the tube and thus rob the flower of its honey Good examples of butterfly-flowers are seen in Red Campion and Ragged Robin, but butterflies also visit many flowers adapted for bees, *most* British butterflies and moths having tongues of about the same length as, or a little longer than, those of bees (about 15 mm)

Some moths, however, have far longer tongues (30 mm in a few British species),[1] which are (as in butterflies) carried coiled up in a spiral under the head when flying These moths can reach honey even when it is at the bottom of a very long tube, as in the Honeysuckle, which is visited chiefly by the night-flying Privet Hawk-moth, and the White Convolvulus, which is said to be pollinated by another species of Hawk-moth (*Sphinx convolvuli*, tongue 80 mm long), and to set seed very seldom in England owing to the rarity of this moth Other flowers pollinated by night-flying moths are the White Campion (*Lychnis vespertina*), Evening Primrose, Tobacco Plant, Privet, Bladder Campion. Moth-pollinated flowers are white or pale-coloured, sweetly scented, and open in the evening, usually remaining closed and almost scentless during the day.

Examine the following moth-pollinated flowers :—Tobacco-plant, Honeysuckle, Evening Campion, Evening Primrose Make and sketch a longitudinal section of each flower Note the condition of the flowers at different times (day and evening), and try to follow all that happens in a single flower from the time it first opens until it finally closes (after being pollinated)

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[1] In some foreign moths the proboscis reaches the astonishing length of 300 mm. (about 12 inches).

354. The Flower-Tube.—It is interesting to compare the various ways in which the flower becomes tubular in form, so as to protect the ovary, to conceal the honey, to shelter the pollen from rain, to exclude short-tongued insects, etc The study of development shows that, starting from the simple "hypogynous" condition, the formation of a "perigynous" or "epigynous" flower, of a "gamophyllous" perianth, of a "gamosepalous" calyx, of a "gamopetalous" corolla, of "epipetalous" stamens, etc, in short, all the cases of "cohesion" and "adhesion" are due to the growth of the receptacle during the flower's development, and that all these conditions in the mature flower are due to differences in the extent of this growth It is important to remember this, as the various terms in current use tend to obscure the facts of development, and even to imply that actual "fusion" occurs after the various flower-parts have been developed

355. Protection against Rain.—The flowers already mentioned show examples of the various ways in which the pollen may be protected against rain Pollen-grains, like seeds, are much less resistant to extremes of temperature and to drying when once they have been moistened and have begun in consequence to germinate In some flowers, especially those whose pollen is exposed to rain when the flower opens, the pollen-grains are not readily wetted, having a covering of wax or of spines, etc In most cases, however, the grains lose their power to germinate if wetted and then allowed to dry

Many flowers protect the pollen by their horizontal or drooping position, *e g* Heaths, Bluebell, Lily of the Valley, Solomon's Seal, Violet, Daffodil In some cases the flower closes up at night or in bad weather, *e g* Wood Sorrel, Tulip, Crocus, Lesser Celandine, Scarlet Pimpernel (in which self-pollination often occurs in the closed-up flower, by the stamens touching the stigma), and the same kind of closing is effected in the flower-heads of many Composites by the movements of the flowers and bracts In Iris the large petaloid stigmas cover the stamens, while in Orchis (Art 352) the single stamen is covered by a hood formed by one of the sepals and two of the petals. Find other examples.

356. Wind-Pollinated Flowers.—Many flowers which contain no honey are visited for pollen by insects, attracted by the colours or scents of these "pollen-flowers." Several examples have been mentioned This leads to the consideration of flowers which have neither honey, scent, nor conspicuous colours, and which are seldom or never visited by insects Such flowers are chiefly pollinated by the wind.

In a few water-plants the pollen is carried by water, and pollination occurs at or below the surface, but this is rare, most aquatic plants raise their flowers well out of the water, and are pollinated by wind (*e g* Pondweed) or by insects (*e g* Water Crowfoot, Water Lilies)

In wind-pollination it is obvious that the chances of a pollen-grain striking a stigma are very small, and that the plant must therefore produce a much larger amount of pollen than is the case in insect-pollination. In order to increase the chances of pollination the pollen is light, and can therefore float for a considerable time in the air and be carried to a great distance, while the stigmas are usually large and branched, to increase the amount of their surface

The anthers are usually carried on long dangling filaments, all the stamens of a flower open simultaneously, instead of successively as in most insect-pollinated flowers, and they either open only in dry weather or are well protected (by catkin-scales, bracts, etc) against rain

In many wind-pollinated trees the inevitable waste of pollen is to some extent reduced by the flowers opening before the leaves have unfolded, or before they have grown large enough to form a serious obstacle to the wind-carried pollen In most herbaceous plants with wind-pollinated flowers (*e g.* Plantains, Grasses, Salad Burnet, Docks, Sorrels) the latter are carried up on a long stalk, well above the leaves, so as to expose them as freely as possible to the wind. It will be noticed that many wind-pollinated plants have the stamens and the pistil in separate flowers, either on the same plant or on separate plants, and that when they are both present in the same flower the stigma nearly always matures before the anthers open, most Grasses, however, are protandrous

From these details and your own observations, draw up a tabular comparison of entomophilous (insect-pollinated) and anemophilous (wind-pollinated) flowers

357. Comparison of Flowers of Willow and Poplar.—Examine and compare the flowers of Willow and of Poplar, which are very closely allied plants In both cases the male and female flowers are on separate plants, and are carried on catkins, each catkin consisting of an axis bearing numerous flowers and each flower standing in the axil of a bract In Willows the male catkins are bright yellow, the female ones green, when the flowers open Each male flower consists of two (in some species more) stamens, with a honey gland at their base, the female flower of a pistil with two stigma-lobes (each often forked at the end), ovary one-chambered with numerous ovules on two parietal placentas, and a honey-gland. The flowers are largely visited by bees seeking for honey and pollen among the scanty spring flowers

In Poplars each male flower has a larger number of stamens (twenty to thirty), surrounded at the base by a cup-like outgrowth ("perianth"), and the female flower of a pistil (similar in structure to that of Willows) with branched stigmas forming a tuft, in neither case is there a honey-gland. The Poplars are wind-pollinated, their flowers have no honey to attract insects More pollen is produced than in Willows, and the stigmas are more branched, exposing a larger surface, the catkins of Poplars hang down loosely and swing in the wind, and are longer than those of Willows, which usually stand out stiffly from the stem Moreover, Poplars flower before the leaves appear, and their flowering is generally over by April, when most Willows are beginning to flower; many Willows flower at the same time that the leaves expand

358. Birch, Hazel, Oak, etc.—Many forest-trees bear their flowers (or at least the male flowers) in catkins, or in clusters resembling catkins, but have the male and female flowers on the same plant In Birch, Alder, and Hazel the male catkins hang down, so that the stamens are covered by the scales (bracts) to which they are attached (as in Poplar), and thus protected from rain The female catkins are smaller, with stigmas projecting beyond the scales. In Hazel and Alder the catkins are formed from special buds, and are nearly mature in the autumn, ready to open early in spring, before the leaves In Birch the female catkins are formed in the ordinary buds, and appear along with the leaves This is also the case with both male and female flowers in Beech and Oak, in which the male flowers have a cup-like "calyx", in Beech the male flowers are in a cluster at the end of a long drooping stalk, in Oak they are scattered along a similar stalk.

Other Wind-Pollinated Flowers—Plants with wind-pollinated flowers occur in some families which are chiefly insect-pollinated —*e g* Meadow-rue (*Thalictrum*) in Ranunculaceae, Salad Burnet (*Poterium*) in Rosaceae Compare their flowers with those of allied plants in the same family Examine also the following wind-pollinated flowers :—

Pine, Larch, Yew.—In these plants the stamens and carpels are on special branches (cones), the pollen is produced in enormous abundance, and the ovules are exposed, so that the pollen-grains reach the micropyle directly

Stinging-Nettles.—Flowers small and green, male and female either on separate plants or on the same plant. In the male flower the stamens are at first folded inwards and downwards, but on warm, dry days they spring up violently and scatter the pollen in a cloud; cut off a branch bearing male flowers, and observe this on touching the coiled-up stamens or warming the flowers Female flower with a tufted stigma (Fig 107)

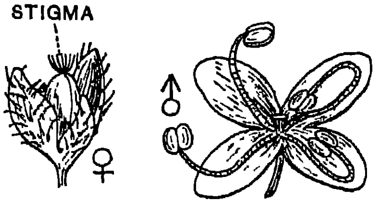

Fig 107 —Male and Female Flowers of Nettle

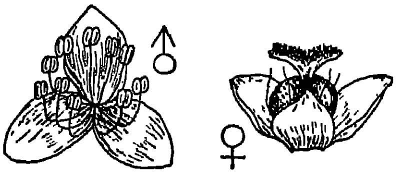

Fig 108 —Male and Female Flowers of Dog's Mercury

Dog's Mercury.—Flowers small, green, dioecious, stamens numerous, two large stigmas (Fig 108) Some honey is secreted, and the flowers are often visited by small insects

Plantain.—Flowers in a spike, markedly protogynous, when the stamens of the lower (older) flowers hang out, after the withering of the stigmas, the stamens of the upper (younger) flowers are still in the bottom of the corolla-tube, and the stigmas projecting outwards and ready for pollination (Fig 98) Some species have coloured anthers, and are slightly scented; these are sometimes visited by insects for pollen

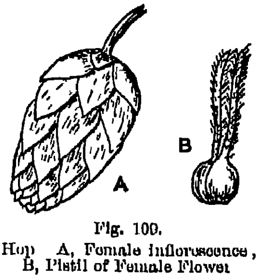

Fig. 109.
Hop A, Female inflorescence, B, Pistil of Female Flower

Other wind-pollinated flowers which you should examine are those of Hop (Fig 109), Sedges, Rushes, Docks, Sheep's Sorrel, Crowberry, Walnut, Oriental Plane, Ash, Elm, Grasses.

QUESTIONS ON CHAPTER XIII

1 What is the usual function performed by the various parts of the flower? Have you observed any cases in which functions other than the usual ones are performed by floral structures? Show by several examples that the division of the flower into four whorls cannot always be rigidly maintained

2 Give an account of the structure and function of a pollen-grain.

3 Describe the processes which lead to the conversion of an ovule into a seed, and state what is the difference between albuminous (endospermic) and exalbuminous (non-endospermic) seeds, giving examples

4 Describe the situation in which honey is produced in any three flowers you have examined. How does it profit a plant to expend its substance in the production of honey? How is it that some plants dispense with the production of honey? Name three such plants

5 Draw the flowers of any three of the following —Figwort, Snapdragon, Foxglove, Salvia, Monkshood, Sweet Pea, Dead-nettle What do you know of the method of pollination in the flowers you draw? Explain the connection, if any, between the methods of pollination and the time of year at which the flowers appear

6 Mention a flower which is naturally self-fertilised, and another which is naturally cross-fertilised. What could you do to aid cross-fertilisation in the first, and self-fertilisation in the second case? Is the seed produced by cross-fertilisation better or worse than that produced by self-fertilisation?

7. Briefly describe, giving examples, the following forms of inflorescence, and point out the relationship which exists between them.—spike, spadix, raceme, head, panicle, umbel

8 State what is the essential difference between *definite* and *indefinite* inflorescences, describing, with examples, the principal varieties of each (definite = cymose, indefinite = racemose).

9. What is meant by a floral receptacle? What part does it play in our conception of the structure of the flower?

10 Name any plants you know in which the flowers are massed in close, flat-topped inflorescences, and mention the advantages which you suppose are obtained by such an arrangement Name any natural orders that are characterised by this type of inflorescence, and describe, with instances, the differentiation (modification) which the marginal flowers may undergo.

11. What flowers have you yourself observed being visited by wasps, by butterflies, by flies? What insects have you yourself seen at Sweet

Pea, Primrose, Buttercup? Supplement this answer by information obtained in other ways, but distinguish carefully between observations and theories, facts and expectations.

12 Describe the inflorescence of a Daisy and of a Dead-nettle, pointing out the features of (*a*) resemblance, (*b*) difference, existing between them

13 Describe the process of pollination in any *two* of the following — Larkspur, Willowherb (*Epilobium*), Dead-nettle, Willow.

14 Describe the flowers of the Primrose, and explain the adaptations for pollination

15. What is heterostylism, and what is its importance? Give examples of heterostyled British plants.

16 Mention any flowers you know which are pollinated by the wind Describe the structures involved in pollination in each case, and show how they differ from the corresponding structures in insect-pollinated flowers Have you noticed any other features of wind-pollinated flowers, such as habitat or time of flowering, which you can connect with wind-pollination? Give instances

17. Name three flowers you have seen visited by flies and three by butterflies and moths How did the insects behave in each case?

18 Name three flowers fertilised by bees in which the essential organs of the flower come into contact with the back of the bee, and three in which they come into contact with its underside Why are bees on the whole better agents of pollination than other insects?

19 Describe fully the differences between insect-pollinated and wind-pollinated flowers, and mention six examples of each class Are the seeds of wind-pollinated flowers generally distributed by the wind or not? Discuss examples

20 What plants may be found flowering (either commonly or occasionally) in the winter months in England out of doors?

21 What *trees* occurring commonly in England have flowers which are visited by insects? You may take examples both from native and from introduced species

CHAPTER XIV.

FRUITS AND SEEDS

359. How Fruits are Formed.—The influence of fertilisation extends from the developing seeds to the surrounding parts, causing a renewal of active growth not only in the carpels, but often in other parts of the flower as well. Usually, however, the stamens and corolla persist for a shorter time than they would have done had not fertilisation occurred

The ultimate result of fertilisation is the formation of a fruit The simplest definition of a fruit is that it consists of the parts of a single flower which persist and grow after fertilisation This definition covers most fruits, which may be divided into *simple* and *aggregate* A simple fruit is formed from one free carpel, as in the Bean, or from several united carpels (syncarpous pistil), as in the Poppy An aggregate fruit is formed from several free carpels, as in Buttercup and Blackberry The wall of the ovary becomes the **pericarp** or fruit-wall, which may, as the fruit ripens, either remain soft and fleshy or become dry and hard

Whether the fruit is dry or fleshy depends on the amount of water it contains when ripe Dry fruits which contain several seeds usually open so as to set the seeds free, the pericarp breaking apart to form an opening Some dry, many-seeded fruits, however, split into pieces, each containing a single seed These two types are distinguished as (1) Opening or Capsular fruits, (2) Splitting or Separating fruits Dry one-seeded fruits, and practically all fleshy fruits, remain closed, and the seeds escape by the decay of the pericarp, or the latter may only be broken when the seed germinates This third type may be called (3) Closed or Indehiscent fruits Indehiscent fruits may be either dry, in which case they are usually one-seeded, or fleshy.

360. Opening or Capsular Fruits.—The **follicle** opens along the inner side (*ventral suture*) which bears the seeds, *e g* in Monkshood, Marsh Marigold, Winter Aconite, Christmas Rose, Columbine, Larkspur (all belonging to the Buttercup family), also in Magnolia, Stonecrop, etc. The **pod** separates into two valves by opening along both the dorsal and the ventral sutures The **siliqua** (characteristic fruit of Crucifers) opens by two valves which separate from below upwards, leaving the seeds on the edges of a partition across the fruit (Fig 110) The **silicula** is a short and broad form of the siliqua (Shepherd's Purse and other Crucifers).

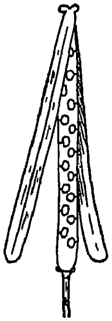

Fig 110 —Fruit of Wallflower.

A typical **capsule** usually consists of several carpels, and is dry The capsules of Horse Chestnut are rather fleshy when ripe, and the fleshy capsules of the Balsam and Wood Sorrel are so much stretched when ripe that a touch is sufficient to cause them to split open and throw the seeds out violently

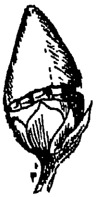

Fig 111 Transverse Dehiscence of Capsule of Plantain

Capsules usually open longitudinally, either along the dorsal sutures (midribs) of the carpels (*e g* Willow-herb, Blue-bell), or (more rarely) along the partitions between the chambers of the ovary (*e g.* Foxglove, St John's Wort). The capsule of Stitchwort and other Caryophyllaceae splits about half-way down into twice as many teeth as there are carpels In all these cases the opening takes place along lines already marked out in the structure of the ovary, but in some plants it follows entirely new paths Thus some capsules open transversely, a lid being separated, as in Plantain (Fig. 111), Pimpernel, Henbane In the Poppy small pieces of the capsule-wall are detached, forming a series of holes around the top of the capsule, through which the seeds escape The capsules of Snapdragon and of Campanula also open by pores.

Examine and make careful sketches of the fruits of Columbine, Monkshood, Larkspur, Winter Aconite, Christmas Rose, Gorse, Laburnum (seeds poisonous), Peas, Beans, Bird's-foot Trefoil, Wall-flower, Candytuft, Shepherd's Purse, Charlock, Willow-herb, Bluebell, Iris, Foxglove, Snapdragon, St John's Wort, Stitchwort, Campion, Chickweed, Plantain, Scarlet Pimpernel, Henbane, Poppy, Canterbury Bell

361. Dry Closed Fruits or Akenial (Achenial) Fruits are given various names, but the chief types are (1) **akene** (or **achene**), with membranous or leathery pericarp—*e.g* Buttercups, Little Celandine, Anemone, Cinquefoil, the akene of Composites (Daisy, Dandelion, etc) only differs in being produced from an inferior ovary; (2) the **grain,** in which pericarp and seed-coat are firmly united—Grasses, (3) the **nut,** with hard pericarp (the term is usually applied to all large or hard-coated akenes)—*e g* Hazel, Oak, Beech, Sweet Chestnut, Hornbeam, (4) the **samara** or winged akene (or nut)—*e g.* Elm, Birch, Ash The akenes of Composites and Valerians often have a tuft of hairs, is usually sessile but stalked in Dandelion and Goat's-beard, called the **pappus** (= calyx), at the top, those of Clematis have a long plume (= style), those of Avens a hooked style

Examine and sketch the fruits of Buttercup, Lesser Celandine, Cinquefoil, Daisy, Yarrow, Dandelion, Groundsel, Thistle, Nipplewort, Goat's-beard, Wheat, Maize, Hazel, Oak, Beech, "Spanish" Chestnut, Elm, Birch, Ash, Valerian, Clematis, Avens.

362. Fleshy Fruits.—A few fleshy fruits open to let the seeds escape—*e g* Horse Chestnut, some Gourds, Balsam. Three chief types of closed fleshy fruits can be recognised. (1) the **berry,** in which the pericarp is soft and fleshy throughout except for the membranous or firm skin, (2) the **drupe,** in which the innermost portion of the pericarp forms a hard stone (endocarp) embedded in the fleshy middle portion (mesocarp), with a membranous skin (epicarp) on the outside, (3) the **pome,** which is intermediate in character between the drupe and the berry, and may be regarded as a special form of the latter

363. Drupes ("stone fruits").—A simple drupe is formed from a single free carpel, and has one stone with one seed inside it—*e.g.* Plum, Cherry Drupes may, however, be syncarpous, in which case each chamber of the ovary may form a distinct stone or drupe. The so-called "berries" of Holly, Dogwood, and Elder are really compound drupes of this kind. The Walnut is a drupe from which the mesocarp (flesh) peels off during ripening, and allows the stone, enclosing a single seed, to escape. The drupe of the Almond has a velvety skin and rather tough mesocarp, which splits along one side; the endocarp is pitted and brittle, and there are sometimes two seeds inside it.

The Coco-"nut" is a drupe in which the mesocarp (removed before exportation) is fibrous. The "shell" is the endocarp, and the flesh inside it is the endosperm in which lies a small embryo (below one of the three pits at the broader end of the "nut"); the fruit is formed from a three-chambered ovary, only one chamber being fertile; the space in the centre of the "nut," filled with sap, corresponds to the cavity (vacuole) in the young embryo-sac.

Examine, dissect, and sketch the fruits of Cherry, Plum, Almond, Holly, Elder, Walnut, Coco-nut.

364. Berries usually contain several seeds, but sometimes only one, as in Dogwood and Date. The Berry is distinguished from the drupe by the fact that the pericarp or "stone" has no hard part, whilst the stone in a drupe is the innermost part of the fruit-wall, and encloses the seed; the seeds ("pips") in a berry may have hard coats, but the fruit has no other hard parts.

The Banana, Currant, Cucumber, Grape, Gooseberry, Orange, Pomegranate, Bilberry, Bittersweet, and Tomato are all berries, although several of them exhibit special peculiarities. In the case of the Gooseberry and Pomegranate, the outer layer of the coat of each seed is succulent, and forms a large part of the fruit. The "quarters" of the Orange, Lemon, "Lime-fruit," and "Grape-fruit" correspond to the carpels, and the juicy part is composed of large hairs, which arise from the walls of the carpels and are filled with watery sap. The "Squirting Cucumber" (*Ecballium*) becomes highly turgid when ripe, so that when it is detached from the stalk the seeds are violently ejected along with a quantity of watery sap.

Examine, dissect, and sketch the fruits of Date, Banana, Gooseberry, Currants, Cucumber, Orange, Grape, Bilberry, Tomato, Bittersweet, Pomegranate.

365. Pomes.—The Apple or Pear affords the best exampl of a pome, being developed from an inferior ovary compose of five imperfectly syncarpou carpels The outer fleshy part of an apple is really a por tion of the receptacle, whil the parchment-like mem brane which forms aroun the wall of each chamber o the ovary is mainly carpellar in origin, the "pips" bein of course the seeds. Pome also occur in Rowan, Haw thorn, Quince, Medlar

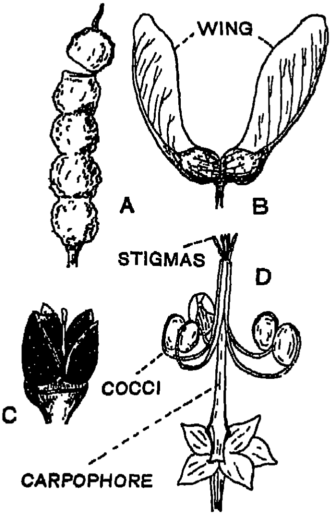

Fig 112 —Schizocarps splitting into several Pieces

A, of Hedysarum, B, of Maple, C, of Lamium, D, of Geranium

Examine, dissect, and sketch the fruits of Apple, Pear, Quince Medlar, Rowan, Hawthorn Cotoneaster

366. Splitting or Separating Fruits (Schizocarps) are so called becaus they split into two or mor one-seeded parts (akenes o nuts) Examples are seen i Sycamore and Maple (Fig 112, B), Umbellifers (Fig 113), Geranium (Fig 112, D), the Labiate and Borage familie (Fig 112, C), Mallow (Fig 114).

In some Leguminosae (*e g. Hedysarum*, the "Frenc Honeysuckle") and some Crucifers (*e g* Radish) the frui splits across into one-seeded pieces, and is called a **lomentum** (more strictly, a lomentaceous pod, or siliqua, as the cas may be), Fig. 112, A

The one-seeded parts into which a schizocarp splits do no usually open to let the seed out; but this does occur i some cases—*e g* Spurges, Geranium

Examine and sketch the fruits of Sycamore, Maple, Cow Parsnip Geranium, Mallow, Dead-nettle, Forget-me-not, Radish, "French Honeysuckle" (*Hedysarum*, cultd.), Spurge.

367. Aggregate Fruits may consist of a number of follicles, as in Christmas Rose, Marsh Marigold, Monkshood, etc , or of a number of akenes inserted on a convex receptacle, as in Anemone or Strawberry, or inside a concave receptacle, as in Rose, or they may consist of drupes on a convex receptacle, as in the Blackberry or Raspberry Notice in each case whether the receptacle is dry or fleshy

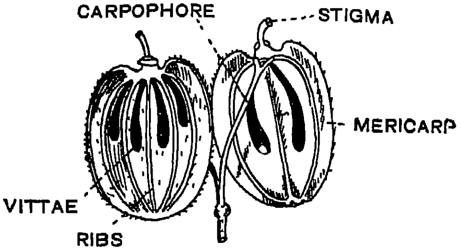

Fig 113 —Schizocarp of Heracleum (Cow Parsnip)

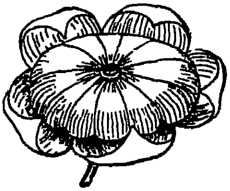

Fig 114 —Schizocarp of Mallow

Examine and sketch the fruits of Strawberry, Rose, Blackberry, Raspberry, Buttercup, Columbine

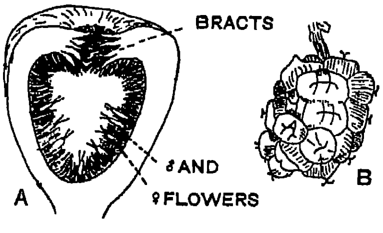

Fig 115 —A, Fruit of Fig cut in half vertically, B, Fruit of Mulberry

368. Special Types.—The fruits developed from a group of flowers or dense inflorescence are often aggregated in closely packed clusters, such as are formed by the fleshy red berries of the Honeysuckle and by the clustered fruits of the Mulberry, the perianths of whose flowers become fleshy and enclose the carpels (Fig. 115, B) The Pineapple is a spike-like inflorescence, in which the axis becomes fleshy during ripening, and the individual fruits fuse together The Hop has an inflorescence consisting of an axis bearing membranous scales, in the axil of each of which there are two female flowers (Fig 109), the scales are shed when ripe with the fruits attached to them. The Fig is formed by a hollow, pear-shaped capitulum bearing male and female flowers, the "seeds" being really akenes (Fig 115, A). The Date is a berry, the hard stone being the seed The Banana is also a berry which, owing to cultivation, does not produce seeds

Examine, dissect, and sketch the flowers of Honeysuckle, Mulberry, Pineapple, Hop, Fig, Banana, Date

369. Dispersal of Seeds and Fruits.—Such a plant as a Cherry tree may produce thousands of fruits and fertile seeds in a single season, although none of the latter may succeed in establishing themselves as young seedlings beneath the shade of the parent tree Even if the parent plant is cut down, or dies at the end of the season, it can hardly make room for more than one or two of its offspring Hence it is of the utmost importance that the seeds should be afforded some chance of distributing themselves, and reaching localities suitable for the development of new trees Animals, and especially birds, act as the dispersing agents in this case, frequently carrying the fruit to a distance, and rejecting the hard stone which protects the seed

Even in the case of annual plants, the dispersal of the seeds is of great importance, for it is evidently impossible that the thousand or so seeds which a single Sunflower may produce can germinate and become healthy seedlings on the same area that the adult plant occupied The means of dispersal adopted by different plants vary widely, and are frequently such as to secure the almost ubiquitous distribution of some plants The four commonest agencies by which dispersal is secured are (1) **wind,** (2) **water,** (3) **animals,** and (4) **explosive** or **ejection mechanisms** in the fruit itself

370. Dispersal by the Wind is facilitated by the minuteness or lightness of the seeds or fruits, and by the presence of tufts of hairs or wing-like membranes which increase the surface exposed to the wind without appreciably adding to the weight It is only in the case of dehiscent fruits that mechanisms for wind-dispersal are borne by the seed, closed fruits and the segments of splitting fruits are themselves distributed and possess contrivances for dispersal, while the seeds have none and are carried inside the fruit. The seeds of Orchids are so small and light that, when they are set free by the dehiscence of the capsules, they are freely blown about by the wind Hence the readiness with which epiphytic Orchids establish themselves upon the trunks of tropical trees.

When the seeds are larger and heavier, the fruit frequently opens in such a manner that the seeds can only escape a few at a time and are jerked out when strong winds rock the capsules to and fro This **censer mechanism** is seen in follicles and many capsules, *e g* those of Poppy and Campanula (Harebell, Canterbury-bell), which open by pores, those of Campions, Stitchworts, Primroses, etc, which open by teeth at the top, besides in capsules opening by slits or a lid; also in the fruiting heads of some Composites which have no pappus on their akenes, *e g* Sunflower

As an aid to wind-dispersal, seeds are frequently flattened (Wallflower, etc), as also are the fruit-segments of Umbellifers and the akenes of Buttercups and Composites.

Very commonly, however, special structures are present which enable seeds, or more frequently akenes, to be more readily carried by the wind The **plumed seeds** of the Willow, Poplar, Willow-herb (*Epilobium*), Bog Asphodel, and Cotton-plant have hairy outgrowths **Winged seeds** occur in Pines, Yellow Rattle, Deutzia, and Bignonia ("Trumpet-flower") The **winged akenes** (samaras) of the Ash, Elm, and Birch afford good examples of winged fruits in which the wing is an outgrowth of the pericarp. In the Maple and Sycamore each fruit splits into two or three winged samaras The Hornbeam has persistent bracts which form a wing on the fruit, a similar bract-wing occurs in the Hop. In the Lime-tree (*Tilia*) the stalk bearing the cluster of nuts hangs down, and the large bract attached to it acts as a kite or aeroplane Bracts also act as wings to the fruits of Bougainvillea and Mirabilis (Marvel of Peru)—two tropical but commonly cultivated plants In Docks the fruit is covered by the "calyx," which bears three wings In some cases the wing is funnel-shaped, or parachute-like, as in Thrift (persistent papery calyx) and Teasel (persistent bracts around the flower)

A few examples of **plumed fruits** (*i e* fruits bearing hairs or hairy appendages) may be given In Clematis, Pasque-flower, and Dryas each akene has a persistent hairy style; in Cotton-sedge the fruit bears numerous long silky hairs, produced by the perianth, in Bulrushes hairs are produced by the stalk on which each fruit is carried The most highly developed plumed fruits occur in Valerians and many Composites; in these plants the calyx grows after fertilisation, and forms a ring of hairs (the pappus) on the top of the fruit Good examples are seen in the Dandelion and the Goat's-beard, where the pappus forms a parachute carried on a stalk If the air becomes moist the parachute closes up, and the fruit falls to the earth, and is washed into the soil by the first shower of rain

Dispersal by wind involves a greater loss of seeds than dispersal by animals, for the latter usually frequent fertile localities where the seeds have a chance of germinating, whereas wind-dispersed seeds may fall upon sterile or unsuitable localities, or may be carried out to sea It is for this reason that winged and hairy seeds are usually absent from the plants of the seashore Hence also arises the fact that wind-dispersed seeds are usually produced in relatively greater abundance than those dispersed by animals

Examine and sketch, with special reference to their adaptations for wind-dispersal, the *fruits* of Poppy, Canterbury Bell, Campion, Stitchwort, Cow Parsnip, Buttercup, Ash, Elm, Birch, Maple, Sycamore, Hornbeam, Hop, Lime-tree, Marvel of Peru, Docks, Thrift, Clematis, Cotton-Sedge ("cotton-grass," in bogs), Valerian, Dandelion, Goat's-beard, Thistle, Groundsel, and the *seeds* of Willow, Poplar, Willow-herb, Pine, Yellow Rattle, Bignonia.

371. Dispersal by Water is uncommon, and occurs chiefly in aquatic plants. Seeds may also be carried on the mud adhering to the feet of aquatic birds In plants which grow on the margin of streams, as well as in those aquatics whose leaves are aerial (*e.g.* Water Plantain, Arrow-head), the seeds may fall into the water In some cases (*e g* Alder) the seeds are enabled to float to a distance by being provided with a spongy covering which contains air This is also the case in Water Lilies, but in these—and in most submerged or floating water-plants—the fruits are developed under water, and are either achenes, nuts, or splitting fruits which separate into hard one-seeded parts

372. Dispersal by Animals may be either passive or active, the seeds may be carried either *inside* or *outside* the animal Many fruits possess hooks, and hence may adhere to the wool or fur of passing animals These adhesive contrivances are usually outgrowths of the fruit and not of the seed Examples are afforded by Avens (hook = persistent style on each akene); Corn Buttercup; Goosegrass, Woodruff, Medick (pod coiled, bearing hooks), Hound's-tongue, Sanicle, Carrot, Chervils, and a few other Umbellifers, Agrimony (hooks on receptacle), Enchanter's Nightshade (Fig 103). The flower-heads of Teasel and Burdock have hooked bracts so that a passing animal may catch the plant and drag it forward, the rebound causing the fruits to be jerked out, or, in Burdock, whole burs (fruit-heads) may thus catch on to the animal and be carried off In Burweed (*Xanthium,* a curious Composite, found in South England but not native, with small heads of unisexual flowers) the female flower-head is covered with hooked prickles and ends in two short conical beaks, and in Bur-marigold (*Bidens*) each akene has a pappus of two or three stiff bristles covered with small downward-pointing prickles The most formidable hooked fruits occur in tropical plants such as Martynia and Harpagophytum, which are usually shown in botanical museums. Hooks and spines also serve to protect fruits against animals which might otherwise eat them, this is probably the case with the spiny capsules of Horse Chestnut, the stiff bristles (awns) of Barley, etc

Active dispersal takes place when animals seek out fleshy fruits in order to devour them. The seeds are protected by hard stones in the case of drupes, or by thick leathery seed-coats in the case of most berries, by the pericarp in fruits such as those of the Strawberry or the Rose. In most cases the covering of the seed is hard and quite indigestible, and in not a few cases the seed itself is poisonous Hence in many cases the seed can pass through the animal's body without being injured, and if deposited in suitable soil may succeed in germinating Very often, however, the hard part of the fruit is never swallowed, but allowed to fall to the ground after the soft part has been pecked, for the animals concerned in this mode of dispersal are usually birds, whose gizzards may crush small seeds and destroy them

The surface of the fruit is usually conspicuously coloured. The pulp or flesh (often sweet and aromatic) may be produced from almost any part of the flower from the ovary-wall (Cherry), the receptacle (Apple, Strawberry), the perianth (Mulberry), etc. Sometimes the seed has a coloured fleshy *aril* or extra seed-coat—*e g* Spindle-tree, Yew, Nutmeg ("Mace" = aril) Most, but by no means all, fleshy and bird-dispersed fruits occur on trees and shrubs (why?)

Dry fruits (Acorns, etc) may also be actively dispersed by such animals as squirrels, etc, for these animals often forget some of the hoards they lay up in autumn This is, however, an accidental mode of dispersal, and, except in the presence of a hard pericarp, the structure of the fruit shows no special adaptations which might render this kind of dispersal more constant and profitable

Collect, examine, and sketch fruits adapted for dispersal by adhering to animals, *e g* Corn, Buttercup, Avens, Goosegrass, Carrot, Medick, Sanicle, Hound's-tongue, Teasel, Agrimony, Enchanter's Nightshade, Burdock In examining fleshy fruits, note which parts are (1) brightly coloured, (2) fleshy and edible, (3) hardened to protect the seeds

373. Explosive Fruits.—Some fruits show active movements by which the seeds are scattered or flung out suddenly These movements often depend upon extreme turgidity in some part of the fruit—*e g* in Squirting Cucumber and Balsams—or of the seed itself In some Balsams the fleshy capsules have swollen and stretched walls, so that a slight disturbance causes the capsule to burst, and the seeds are thrown a few feet away

In some dry fruits the ejecting mechanism depends upon tensions set up by the drying of the fruit wall. In Pansies and most Violets the flower-stalk grows up erect after pollination has occurred, and the ripe capsule splits down, midway between the three lines of seeds, into three boat-shaped pieces, and as these dry they contract and squeeze the seeds together; the pressure causes the polished and slippery seeds to be flicked out forcibly and thrown to a considerable distance (sometimes as much as six feet in Garden Pansies), just as one can flick a slippery orange seed by pressing it between finger and thumb.

In Geranium (Fig. 112, D) the carpels split apart, and the style splits off a slender thread attached to each carpel; these threads suddenly curl upwards and outwards, so as to throw the seeds out. The ripe pods of Gorse, Broom, Lupin, etc., suddenly burst open, the two valves becoming twisted and the seeds scattered. More or less similar explosive mechanisms occur in various other plants.

(*a*) In ripe fruits of Wood Sorrel notice that some of the chambers may be empty; if so, find the slit through which the seeds have escaped. This suggests that the seeds are in some way forced out of the chambers, the longitudinal slit running down the middle of the chamber-wall closing up again at once. How do the seeds escape? Try squeezing ripe fruits between the fingers until you succeed in causing seeds to spring out. How far may a seed be jerked away? By carefully examining (1) a ripe fruit with the seeds still inside, (2) a fruit from which the seeds have escaped, (3) the seed itself both before and after its escape, you should be able to discover that the seed has a thick fleshy extra coat (*aril*) covering it like a cup, and that this coat, by suddenly turning inside out, causes the seed to be shot out of the fruit through the slit in the chamber-wall.

(*b*) Examine and sketch the fruits of Violet, Pansy, Geranium, Gorse, Broom, Lupin, Box-tree, Spurge, Hairy Bittercress. Try to find out how the seeds are ejected in each case.

374. Practical Work on Fruits and Seeds.—Collect all kinds of fruits, belonging to both wild and cultivated plants, and arrange them according to (1) their structure, (2) their adaptations for seed-dispersal. Make sketches of all the fruits you examine; cut them across or open them up to make out the structure. Distinguish between one-seeded fruits (akenes, etc.) and true seeds, and notice which part of a fruit is fleshy, which part forms wings or tufts of hairs, etc. Carefully notice and compare the times taken for a winged or plumed fruit or seed to fall to the floor (1) with the wings or plumes still on it, (2) after removing them. Watch the scattering of flattened, winged, and plumed fruits and seeds on a windy day Why do some winged fruits—*e g* Ash- and Sycamore-"keys"—whirl round while being blown away, and what are the advantages of this?

The structure of small seeds is best made out by the examination of thin sections Rather puzzling appearances are, however, presented when the embryo is curved or twisted instead of being straight, or when the cotyledons are folded, or divided into lobes, for in such cases the same part may be cut twice in the one section

In some seeds special outgrowths or **arils** are formed at the point of attachment of the seed and funicle, or from the surface of the seed. These assume the form of wartlike, fleshy excrescences in the seeds of the Pansy, Castor Oil plant, and the Spurge In the Willow and Poplar the aril is represented by a tuft of hairs which grow out from the funicle Occasionally the aril forms an irregular fleshy investment to the seed, an example of which is afforded by the mace of Nutmegs. The succulent part of the red "berry" of the Yew is simply a special kind of aril, as is shown by its mode of development

QUESTIONS ON CHAPTER XIV

1 Distinguish between syncarpous and apocarpous fruits, and give examples of common table fruits under both heads

2 Compare carefully the flower and fruit of a Rose with those of a Buttercup, and explain, by means of diagrams, the principal differences between them

3 Show by comparative drawings of the flower and fruit of the Apple, the Rose, the Blackberry, the Plum, and the Strawberry just what parts of the flower and fruit correspond to one another in each case

4 Mention two plants, each of which possesses a persistent calyx. Fully describe the calyx, and explain its use to the plant in both cases

5 Describe and compare the fruits of the Rose, Fig, Strawberry, and Mulberry

6 Give instances of seeds or fruits which are dispersed (*a*) through the agency of the wind, and (*b*) through the agency of animals. Of what advantage is it to plants that their seeds should be thus dispersed?

7 Describe examples of fruits or seeds which are dispersed by water, pointing out any adaptations for this method of dispersal

8 Give an account of the various ways in which seeds are protected during the period of ripening

9 Describe with the help of drawings five different devices by which seeds are scattered Describe any experiments you have made on the scattering of seeds

10 Mention any fruits or seeds you know which are distributed by the agency of animals Describe the structures used in five cases Have you made any personal observations on such distribution ?

11 Write a short account of the structure of the more common dry dehiscent fruits, and explain how the seeds are scattered in those examples which you describe

12 Describe examples of explosive fruits, and try to explain the mechanism in each case

13 Describe the following fruits —Plum, Strawberry, Raspberry, Apple, and Orange What is the nature of the edible portion in each case ?

14 How are the seeds of Cherry, Field Geranium, and Pine or Birch dispersed ?

15 Describe in detail, with careful drawings, the parts of the plant used in the distribution of seed, in four cases observed by yourself, in which the seed is distributed by the agency of animals How do the fruits whose seeds are thus distributed differ from those distributed by wind ?

16 How do you know that a Strawberry "pip" is a fruit, while a Gooseberry "pip" is a seed ? Mention any other "pips" you know, with drawings of three cases showing the surrounding structures, and say in each case whether the "pip" is a fruit or a seed. How are "pips" usually distributed ?

17 Give a concise life-history of any one annual plant that you have grown throughout the year, with approximate dates at which the different organs appeared, stating at the same time the conditions under which it was grown If possible, give sketches of the different phases of development

18. Trace the life-history of any plant, living for more than a year, which you have carefully tended under cultivation from seed and back again to seed

CHAPTER XV.

THE BEAN FAMILY

375. The Study of Typical Plants.—In the following chapters we shall study various common plants as "types" of certain orders or families **Each of these plants should be studied throughout its life history.** The best way is, of course, to make repeated visits to the growing plants at short intervals, day by day (and at different times of the day in some cases), week by week, month by month, throughout the year In any case—more especially if these frequent visits cannot conveniently be made—dig up the smaller plants and keep them under continuous observation, indoors or in a garden, making notes and sketches of the various stages in the progress of the plant's growth and development Sow the ripe seeds of each plant and study the stages of germination and the growth of the seedling into the mature plant Carry out all the experiments mentioned in connection with each plant and any others which suggest themselves as being likely to yield answers to the questions arising from the study of the plant itself

Many plants which do not grow wild in Britain, or are rarely met with as wild plants, are grown in gardens, or can be bought from nurserymen. If possible get the "roots" or bulbs and grow the plants, or sow their seeds.

Among the many points to be attended to, the following may be mentioned —

(1) The habit (form and general appearance) of the plant—*e.g* tree, shrub, climbing, creeping, rosette-form, erect herb, bulb-forming—and the advantages and disadvantages of the habit.

(2) The habitat (place of growth)—*e.g* hedge-row, field, marsh, ditch, pond, stream, wood—and the adaptations to the habitat.

(3) The conditions of growth as regards soil—*e.g.* sand, clay, loam, chalk, moistness or dryness of soil, presence or absence of humus.

(4) The light-conditions—whether deeply or partially shaded or in full light.

(5) The associated plants and *their* habits and adaptations.

(6) The characters of the vegetative organs of the plant—*e.g.* methods for reaching light and air, for spreading by runners, etc., for perennating, storage of food, form and texture of stem and of leaf, hairiness or smoothness, buds (structure, form of young leaves, unfolding), arrangement of leaves, form of blade, lengths of leaf-stalks, movements of young or adult leaves, abundance or scarcity of stomates on upper and lower surfaces of leaf, methods by which young or adult leaves are protected against excessive transpiration, etc., leaf-mosaics.

(7) The characters of the reproductive organs (note any means of vegetative propagation apart from the production of seeds)—*e.g.* time of flowering, colour, scent, honey, mechanisms for promoting cross-pollination, kinds of insects seen visiting the flower if insect-pollinated, adaptations for insect-visits or for wind-pollination, movements of flower-parts or of flower-stalks and the reasons for the movements, structure of flower (dissect, cut longitudinal section, and draw these and also the ground-plan or "floral diagram" of the flower), stages in development of fruit, growth of ovary-wall after fertilisation and any changes in its texture and colour, growth of other parts (calyx, receptacle), structure of ripe fruit (sketch whole fruit and sections), time when fruit ripens, number and size of seeds, proportion of seeds to ovules, adaptations for seed-dispersal by birds or other animals, by wind, by mechanisms for ejection; whether the plants grow singly or in colonies.

For various special points in the biology of trees and shrubs see Chapter XXV. Where small-type descriptions are enclosed in square brackets [ ], it means that the plant is not a native of Britain.

The following abbreviations are used in the Notes on Common Plants in the succeeding Chapters:—

A, andrœcium (stamens).
alt., alternate.
Brit., British Isles.
C, corolla.
cf., compare with.
cpl., carpel.
comp., compound.
cultd., cultivated.
distd., distinguished.
esp., especially.
exc., except.
flr., flower.
G, gynœcium (pistil).
gen., generally.
inf., inferior.
infl., inflorescence.

K, calyx.
loc., loculus.
-loc., locular.
opp., opposite.
P, perianth.
per., ,,
rec., receptacle.
reg., regular.
repd., represented.
repg., representing.
sta., stamen, stamens.
zygom., zygomorphic (irregular).
♂, male.
♀, female.
⚥, hermaphrodite.

376. Sweet Pea (*Lathyrus odoratus*, cultivated) —We have already studied the germination of the seed Get complete plants and study the stem, leaves, flowers, and fruits

Note the green flattened stem, which is provided with a thin expansion (wing) on two opposite sides Do the wings run straight along the main stem, always on the same sides?

Sketch a piece of the shoot bearing a leaf, note the stipules, the two leaflets, and the tendrils. What part of a leaflet does a tendril represent? What part is not developed in one of these leaflet-tendrils? Compare the ordinary leaf of Sweet Pea with the *early* leaves (Fig 6) of Broad Bean What advantage does the Sweet Pea lose by the development of its upper leaflets into tendrils? How is the loss of green tissue in this plant to some extent compensated? Examine the Everlasting Pea, which differs from the ordinary kind in being perennial (note the branched underground stem, and test its cut surface with iodine solution), how does its leaf differ from that of the common Sweet Pea? What is the advantage of the winged leaf-stalks in Everlasting Pea?

Why does a Sweet Pea seedling fall over and sprawl about if no support, *e g* a stick, is placed near it? Place sticks in a pot of seedlings, also strings stretched between sticks and running horizontally and at different angles Are the tendrils able to coil around horizontal supports as well as inclined or vertical supports? Sketch a young leaf with tendrils which have not yet come into contact with a support are the young tendrils straight or curved? Is it possible to make a young tendril coil without providing it with a support? Try the effect of stroking a young tendril with a stick, a string, a glass rod, stroke it at different points Which part of the tendril is sensitive to contact and responds by coiling? Make similar experiments with the tendrils of Passion-flower and Vegetable Marrow, these are modified *branches*

Examine flowers of different ages, making observations as directed for Broad Bean (Ch I). Dissect and sketch the flower and follow its development as fully as possible, from the time it opens until the ripening of the pod The mechanism of the flowers is essentially similar to that found in the Broad Bean, but self-pollination usually (probably *always*) occurs in the bud before the flower opens, verify this for yourself See Art. 394

377. The **Peas** or **Vetchlings** (*genus Lathyrus*) are easily distinguished from the **Vetches** (Art 378) In *Lathyrus* the leaflets are few, often 1 or 2 pairs, while in the Vetches there are usually at least 6 pairs. The commonest wild Pea with one pair of leaflets is the **Meadow Pea** (*L pratensis*) which has large arrowhead-shaped stipules, leaflets 10 to 30 mm long, trailing or climbing stems 1 to 2 ft. long, short tendrils, and 4 to 10 yellow flrs (June-Sept.)

Wood Pea (*L sylvestris*, probably the parent of the Everlasting Pea), not common, is larger (up to 5 or 6 ft), with longer leaflets (10 to 15 cms.) and tendrils and red flrs

The **Tuberous Pea** (*L macrorhizus*), in woods and hedges, has a tuber-bearing rhizome, 2 to 4 pairs of leaflets, small (5 mm) stipules, no tendrils (petiole ends in a point), and 2 to 4 crimson flrs. (June-Aug) which fade to green or blue

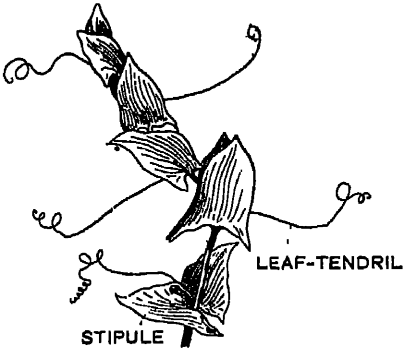

Fig. 116 —Yellow Vetchling (*Lathyrus aphaca*).

The **Yellow Vetchling** (*L. aphaca*), in cornfields and waste places, all the leaflets are developed as tendrils (Fig. 116) and the stipules are large (10 to 30 mm. broad) and leaf-like (why ?) , stems trailing (1 to 3 ft long) ; flrs. (June, July) singly or in pairs on flowering branch, 15 mm. long, pale yellow, the early leaves of the *seedlings* have oblong leaflets.

In **Grass Vetch** (*L nissolia*, found chiefly in the south of England) the plant appears to have long grass-like leaves, but close examination shows that the apparent leaf is really a flattened leaf-stalk, with two minute stipules at its base, and no leaflets are present The Grass Vetch does not climb, but it grows among grasses and gains some support in this way , does its growth among grasses explain the long narrow form of its flat leaf-stalks (technically called *phyllodes*) ? The crimson flrs (May, June) are borne singly or in pairs on a long stalk.

378. Vetches.—The true Vetches are allied to the Broad Bean, forming the genus *Vicia* The **Common Vetch** o **Tare** (*Vicia sativa*), or one of the other species, should b studied as a type, the Vetches differ from the Broad Bea (*Vicia faba*) in being tendril-climbers, like the Sweet Pea.

The Common Vetch has long been cultivated for fodder and has become so widely distributed that besides growing i cultivated fields it is frequently found in waste places an woods. It is sometimes sown with Rye, the stems of whic serve as supports for the tendrils. It is easily distinguishe from the other Vetches by its red flowers, carried singly or i pairs in the axils of the upper leaves, and the dark spot a the centre of each stipule.

Examine plants found in fields, hedge-rows, and othe localities, noting whether the stems are short and spreadin or long and erect. Sketch a piece of the plant, showing th form of the stem, the leaves, each having 3 to 6 pairs o leaflets and ending in tendrils (modified leaflets); the flower (spring and early summer) and the pods. Examine th flower (April to June) carefully and compare its structur with that of the Broad Bean and the Sweet Pea, note th tuft of hairs below the stigma, which is one of the character separating the Vetch-and-Broad-Bean genus (*Vicia*) from th Pea-and-Vetchling genus (*Lathyrus*).

379. Of the other Vetches found in Britain the two commonest a the **Tufted Vetch** (*V cracca*) and the **Bush Vetch** (*V. sepium*). Th former, which flowers from July to September, is the most conspicuou of the wild Vetches, owing to its large masses of purple flowers an the height (6 ft or even more) the plant reaches in climbing the hedges It is a perennial plant, with a creeping "rootstock"; the leaf ha numerous pairs of leaflets and ends in two or three tendrils, and th stipules are half-arrow-shaped The inflorescence (a *raceme*) bea numerous flowers, each with a short stalk, and the flowers are turne towards one side of the inflorescence; this arrangement enables a be visiting the inflorescence to visit several flowers in a short time

The Bush Vetch flowers from April until October; it often grows i woods and on roadsides as well as in hedges. Like the Tufted Vetc it is perennial, but the stems are seldom over 2 ft. high, and the flower (2 to 6) are in a very short raceme (as in Broad Bean).

In Tufted Vetch each wing-petal is united to the keel in two places more firmly than in Broad Bean and Sweet Pea; the mechanism i similar, but the parts resume their former position more readily whe the pressure is removed, i e, when the bee leaves the flower. Th flowers are small and visited by various insects, short-tongued as well as long-tongued In Bush Vetch the flower-tube is longer and the flowers are therefore visited by fewer insects; apparently even humble-bees have to (or at any rate often do) bite through the side of the flower to get the honey

In most Vetches the pod opens violently and expels the seeds, the two valves coiling suddenly as in Gorse and Broom.

380. White or Dutch Clover (*Trifolium repens*) is the commonest kind of Clover and is easily distinguished by its slender creeping branches (runners) and its ball-like clusters of cream-white flowers (May to October)

Pull up an entire plant, noting the wiry green runners which arise from the parent plant and creep in all directions, giving off at certain points ("nodes") a leaf and often a root. The roots, though slender, penetrate deeply into the soil; dig a root up, wash it, and notice the numerous tubercles, which are nearly always present on it, and the length of the much-branched root Note the arrangement of the leaves in two side rows on the stem, and the bending of the leaf-base which brings the stalk into a more or less vertical position. Examine plants growing in different localities, *e g.* on waste ground, in garden borders, on lawns, on garden paths, under hedges, among long grasses, in exposed places, in dry or sandy soil, in moist rich soil

The White Clover has several obvious adaptations or advantageous characters which enable it to struggle successfully for existence, as, indeed, *all* plants have. Its long runners enable it to spread rapidly along the ground, while its long roots reach a deeper water supply in the soil than do the roots of most grasses and other plants with which it has to compete. Its leaves can be altered in position by means of the leaf-base, which is capable of changing in shape so as to alter the direction of the leaf-stalk; the latter varies greatly in length, remaining very short when the plant is growing with short grasses, as on a close-cut lawn, but growing very long when among longer grasses, while the three leaflets spread out like an umbrella and catch plenty of light The Clover is evidently a light-demanding plant, and it grows badly when overshadowed by long grasses in a field or by a hedge

Now compare the appearance (length of runners and of leaf-stalks, size of leaflets—in short, the general "habit") of plants growing in different localities and see whether your observations bear out what has just been said about the biological advantages possessed by White Clover Do not be content with merely reading about adaptations of plants, when it is easy to find out so much for yourself

Note the three leaflets, arising close together from the top of the leaf-stalk, the swollen base of each leaflet, the shape of the leaflet—broadest at the free end ("obovate" or "obcordate"), the white spot or Λ-shaped patch at the middle of the leaflet, the midrib and the finer veins Dip a leaf into boiling water· air-bubbles escape from both surfaces, and the white patches disappear This shows that the leaflets bear stomates on both sides, and that the white patch is due to the presence of air Microscopic examination of pieces of skin torn from a leaflet and of sections across a leaflet shows that there are numerous stomates on both surfaces (rather more on the upper surface than on the lower) and that the whiteness of the patch is due to reflection from a layer of air below the skin, which is separated here from the inner tissue of the leaflet.

Note the small pointed stipules, which are joined around the stem at the base of the leaf-stalk. Examine the growing free end of a runner, and note how the stipules enclose and protect the youngest leaves and the growing-point of the runner Note also the way in which the three leaflets of a young leaf are separately folded up does the folding bring the upper or the lower faces of each leaflet together?

Have you ever noticed that Clover leaves become folded up at night? The "sleep" movements of Clover are easy to observe if you visit the plants at dusk, or later with a lantern, and in addition make a few simple experiments. In the sunlight the three leaflets spread out more or less horizontally from the top of the leaf-stalk When closing begins, the leaf-stalk becomes erect, then two of the leaflets rotate through 90° until they stand in the vertical plane, with their upper surfaces in contact, and finally the third or "end" leaflet swings over, describing a complete semi-circle and at the same time becoming folded along its midrib so as to cover the other two leaflets like a roof, its lower surface being of course on the outside. The result of these movements is to conceal the upper faces of all the leaflets, at the same time bringing them into the vertical position.

From your knowledge of plant physiology, you will realise the usefulness of these movements as a protection against excessive loss of moisture and of warmth If the leaves are prevented from moving, and caused to remain in the horizontal position, by being pinned to a piece of cork, they lose water and warmth, and (especially on a clear cold night) may be injured or even killed Clover leaves fixed in this way show drops of dew on the leaflets when examined in the morning, while untouched leaves remain quite dry

Several questions arise from observation of the sleep movements of Clover leaves, and these questions can be answered, *partly* at any rate, by a few simple experiments

First, to what external stimulus, or stimuli, are the movements due? If it is darkness alone which induces the movements, it should be possible to make the leaves "sleep" in the daytime by covering up a plant so as to exclude light from it Invert a flower-pot over a Clover plant growing out of doors, heaping soil around the rim so as to keep light out. How long does it take for the leaflets to assume the night position? The experiment can be made indoors with a plant dug up and put into a flower-pot, or even with single leaves cut off and set in a bottle of water If you have a pair of coloured bell-jars (red and blue), or, better, a pair of hollow bell-jars containing coloured solutions (see Art 214, *b*), you will find that the plants receiving red-orange light show the "sleep" movements, while those in blue-violet light do not—red-orange light acts in this case like darkness, blue-violet light like sunlight

Has *cold* any share in causing the movements? Get two dug-up Clover plants and set them in glass jars, surrounding one jar with pieces of ice, then expose both to sunlight. Another method is to use single leaves, putting some into a bottle containing water kept cold by adding pieces of ice, while the water in the other bottle is at the ordinary temperature. Does warmth hasten the "opening" of leaves which have assumed the night position? Try a simple experiment with "closed" leaves, setting some in warm and others in cold water.

Second, by what mechanism are the movements caused, and where do they take place? If you carefully examine leaves in different stages of movement, you will find that the broad thin parts—the blades—of the leaflets do not change in form (except for the folding-up of the end leaflet to form a roof over the other two), so that the actual movement has its seat in the short cylindrical stalk which joins the leaflet to the main leaf-stalk This can be proved by (1) clipping a leaflet off just above its base, (2) clipping away the thin green portion of the blade of a leaflet and leaving only the midrib In both cases the parts left will perform the movements, as if the leaflets were still present. For comparison with Clover, study the sleep movements of the Wood Sorrel.

The flowers of the Clover are arranged in globular heads, 15 to 40 mm diameter, each head being carried on an erect branch, usually from 7 to 15 cms long, which arises in the axil of a leaf The calyx-tube is colourless, with five green pointed teeth rather shorter than the tube itself, the lowest tooth being the shortest The petals are white, creamy, or reddish in colour, the wing-petals are joined firmly to the keel.

The corolla is short enough for hive-bees to reach the honey (Clover forms an important source of honey, like Ling, Winter Aconite, and Crocus). When the keel is pressed down the stamens and stigma emerge from it, but they resume their former position when the bee flies away, so that the same flower may be visited several times Each flower has a short stalk of its own, and after the flower has been pollinated the stalk lengthens and bends downwards, so that the pollinated flowers are placed out of the way of the bees and room is made for the younger flowers.

The pod, containing 2 to 4 seeds, projects beyond the calyx, but is covered by the withered standard-petal.

381. Red Clover (*Trifolium pratense*) differs a good deal from White Clover It is a larger, coarser, and more compact plant its "rootstock" or "rhizome" is short and thick, its leafy shoots are covered with soft hairs; its leaves and flowers (May to September) are larger.

Dig up a plant, noting that all the spreading aerial shoots arise from the thick main stem ("rootstock"); cut the latter across and test the cut surface with iodine solution, noting the abundant starch. The plant is perennial, but generally lasts only a few years. The leafy shoots, which may reach a length of two feet, bend outwards from the "rootstock," but soon grow erect, giving the whole plant a tufted habit The stalks of the lower leaves are long, those of the upper leaves short. Notice the large stipules (often 2 or 3 cms. long), continuous with the sheathing leaf-base, each has green streaks (veins), ends in a long pointed tip, and is hairy outside while the inside is smooth and shiny. Pull off the leaves from a bud or young leafy shoot and notice how the stipules protect the young leaves The leaflets are folded along the midrib so that the upper surface of each is on the inside of the fold. The leaflets (2 to 5 cms. long) are oblong, with the edges finely toothed; there is usually a Λ- or λ-shaped whitish patch about the middle.

The flowers are in dense globular or egg-shaped heads (diameter 2 to 4 cms), and are usually red-purple, but sometimes very pale red or even white A little below the head there are two leaves differing from the ordinary foliage-leaves in having no stalk or a very short one and in having larger stipules, these two leaves fold over and protect the young flower-head. Just below the flowers there are several very small bracts covered with silky hairs. The flower is about 2 cms. long, the colour is chiefly due to the standard. The calyx-tube is short and has five narrow pointed hairy teeth, the lowest tooth is much longer than the others. The wing-petals are longer than the keel, the keel-petals are firmly joined along the bottom of the keel, and the claws of the four petals are joined to the stamen-trough. The standard is free, as is also the uppermost stamen All the anthers are alike in size and position The flower contains abundant honey, as can be ascertained by a very simple experiment, it has been called "Meadow Honeysuckle"

Red Clover is visited by bees (chiefly humble-bees) and butterflies (*e.g.* "Clouded Yellow"), the tube is rather too long for the shorter-tongued bees (*e g* hive-bees) The stamens shed the pollen before the stigma is ready to receive pollen. The ovary is small and rounded, the style long, the pod contains only one seed as a rule, and the top generally comes off like a lid The calyx persists around the pod and its five teeth spread out, the corolla withers, but remains on the plant instead of falling off.

382. Various other species of Clover (*Trifolium*) grow, wild or cultivated, in Britain. The **Zigzag Clover** (*T medium*) is like Red Clover, but is less hairy, has straggling zigzag stems, rather larger and brighter flrs. (June-Sept.), and the pod opens longitudinally; **Hop Clover** (*T. procumbens*) has small yellow flrs (June-Aug.) on a dense globular axillary long-stalked head (30 to 50 flrs), **Lesser Clover** (*T. minus*) is similar, but has smaller heads (10 to 20 flrs.) and smaller flrs ; **Strawberry Clover** (*T fragiferum*) has also globular heads, but small rose-purple flrs. with a series of bracts below them, **Hare's-foot Clover** (*T. arvense*), in dry fields, has oblong heads and is covered with silky hairs, the hairy K-lobes are longer than the C. of the tiny flrs. (July-Sept). There are several other less common wild species

[**Crimson Clover** (annual, flrs in oblong heads) and **Alsike Clover** (perennial, flrs white or rosy in globular heads, like White Clover but flrs smaller and pod only 1- or 2-seeded) are commonly grown in fields]

383. Scarlet Runner (*Phaseolus multiflorus*) —We have already examined the seed and seedling of this well-known plant The ease with which one can obtain vigorous young plants from seed makes the Scarlet Runner a very convenient plant in which to study the process of climbing by means of a twining stem It is a native of Mexico.

Grow a seedling in a pot until the upper part of the shoot hangs over horizontally for a few inches. Tie the lower part of the stem to a stick placed in the soil, set the pot on a sheet of paper and record the position of the tip of the shoot. This may be done in several ways —(1) by drawing lines on the paper radiating from the centre of the pot, so as to show the direction in which the stem-tip points; (2) by using a plumb-line (a string with a weight tied at one end) and marking the spot on the paper below the stem-tip, (3) by fixing a sheet of glass over the plant and marking on it the position of the stem-tip. Whichever plan is used, record the time when each observation is made, and find out how long it takes for the stem-tip to swing round through a complete circle In which direction does the shoot revolve—with the hands of a clock[1] or in the opposite direction?

We know that warmth hastens the rate of growth of plants does it hasten the rate of revolution of a climbing stem? Compare the times taken by the same plant to make a complete revolution when kept first in a warm place and then in a cold place, or *vice versa*. At 33° C. a Runner plant revolved in 2 hours 20 minutes, while at 24° C. the plant took 3 hours 25 minutes to revolve.

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[1] The terms "with the sun" and "against the sun" are sometimes used instead of "clockwise" and "anti-clockwise" The plant (placed between sun and observer) points successively to East, South, and West in revolving "with the sun"; this occurs in the Hop and Honeysuckle. The plant points successively to West, South, and East in going "against the sun," *i.e.* in the anti-clockwise direction, this occurs in most climbers, *e.g.* Scarlet Runner, Convolvulus.

Get several vigorous plants ready, each in its own pot.

(1) In one pot set a long stick in a vertical position near the plant Note that the stem swings round and stops at the point where it touches the support, while its free end goes on revolving, in this way it finds a support and then goes on growing upwards

(2) Must the support be vertical? Try the effect of setting the stick in an inclined position, in one pot at 30° from the vertical, in another at 45°, and so on The Runner, like most other twiners, cannot, as a rule, climb up a stick set at more than 45° from the vertical The Convolvulus will twine around a horizontal stick.

(3) What happens if you remove the stick before the shoot has made any coils around it? If you do this carefully, you will see that the shoot springs forward, showing that it has been pressing against the stick, then it becomes straight and starts again to revolve.

(4) What happens if you remove the stick after the shoot has twined round it for a day or two? Notice that now the shoot keeps its spiral form and does not straighten itself out.

(5) What happens if a thick stick or other thick support is used instead of a thin one? Use a large flower-pot or a box for this experiment, and place in it, near the plant, a thick cylinder of wood or a tube of cardboard or paper, try supports of different thicknesses (diameters of 2, 4, 6, 8, 10 inches). The shoot will not twine around a thick support (about 4 inches diameter), evidently because the support is not curved strongly enough to enable the shoot to hold on while the growing free end swings round the support.

(6) In what part of the shoot does the twining take place? Cut off the uppermost part of a shoot, just above the youngest expanded leaf The shoot still revolves, even though several of the upper "internodes" be removed It will be found, however, that the *lowest* "internodes" will not twine round the stick; it is only the upper (younger) parts which revolve.

(7) Does the stem become twisted as it revolves? From the external appearance of the stem and from the positions of the leaves, it would seem that twisting does occur. The

best method of observing this is to paint a line along the convex side of the stem and to watch what occurs during a revolution The line is seen to run round the stem, so that at the middle of the revolution it is on the concave side, while at the end of the revolution it is again on the convex side. The explanation is that the growth of the stem is not equally rapid all round, a wave of rapid growth passes round the revolving free part of the stem. It would appear that the revolving movement of twining plants is due to a response to the stimulus of gravity, for no twining occurs when these plants are rotated on a clinostat (see Art 277) The painted line is, after a few revolutions round the support, seen to be twisted round the stem from left to right, the twist probably makes the stem stronger, just as a much-twisted rope is stiffer than a loosely-twisted rope

(8) Will the Runner climb up a very *smooth* support? Use a piece of glass tubing instead of a stick, the plant will climb, provided the tube is not too thick, but the twisting of the stem will be much less than when a rough support is used.

(9) Will the Runner climb up a piece of string, tightly-stretched or slack? It will be very easy to devise experiments to answer this question

Note the thinness of the stem, which is not nearly strong enough to stand erect In seedlings notice that the first "internode," *i e* the portion of stem between the cotyledons and the pair of large simple foliage-leaves, grows erect, while the region above these first foliage-leaves soon begins to bend over and to revolve Note the compound leaves, each with three leaflets, which succeed the paired simple leaves; the stipules at the base of the main leaf-stalk, the very small stipule-like appendages at the bases of the individual leaflets, and the dark-green swollen leaf-base (*pulvinus*) The leaf shows sleep-movements, not nearly so marked as in Clover, but still quite easy to observe, especially in young leaves. The three leaflets droop and place themselves more or less vertically, the two lower leaflets approaching each other with their lower surfaces, at the same time the main leaf-stalk also moves downwards (owing to curvature of the pulvinus), so as to bring the leaflets into the vertical position Bend the stem so that the lower surface of a leaf is uppermost, and notice at the end of two or three days that the pulvinus has bent until the leaf assumes its normal position, the individual leaflets adjusting themselves in a similar manner, while in the upside-down position, the leaf still performs "sleep" movements, but these are reversed as regards the plant, *i e* the leaf bends upwards at night, showing that gravity is partly concerned in causing the movements in the Scarlet Runner at any rate

Examine the flower (July to Nov.) Note the brownish bracts, one at either side of the calyx, which has an upper lip with 2 very short lobes and a lower lip with 3 longer lobes; the curiously coiled keel, rolled up like a snail-shell and enclosing the similarly coiled stamens and style; the scale on the upper side of the broad base of the free uppermost stamen; the large yellowish collar-like nectary at the base of the ovary.

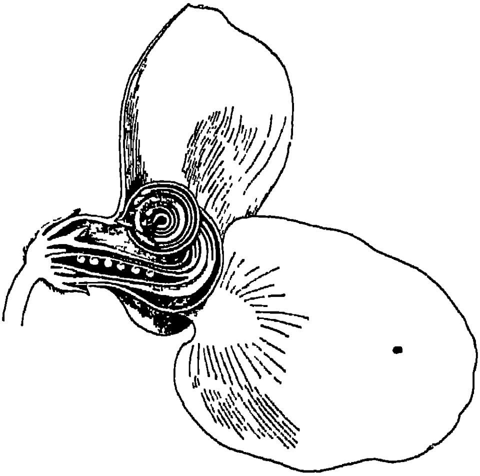

Fig 117.—Longitudinal Section of Flower of Scarlet Runner.

Carefully sketch (1) side-view of parts seen after removing the calyx; (2) side-view after removing one wing-petal and half of the standard petal; (3) longitudinal section of entire flower (Fig. 117).

Bees alighting upon the wing petals press them downwards and at the same time depress the keel to which they are attached. This causes the style to protrude and the hairs upon it sweep out pollen on to the base of the bee's proboscis Before this happens, however, the latter has already touched the exposed stigma (which projects slightly from the tip of the keel), probably depositing pollen upon it from another flower The exposure and retraction of the style may be repeated several times, and can easily be produced by pressing the lateral petals downwards This flower is so highly specialised for cross-pollination that if protected from bees by a gauze net it rarely sets seed.

384. Common Gorse (*Ulex europaeus*), also called **Furze** and **Whin,** usually grows in large patches, often forming the chief or "dominant" plant in the vegetation of heaths. Though generally forming a shrub from 2 to 5 feet high, it sometimes grows into a fairly strong and erect "tree," especially when in a sheltered situation.

There are three kinds of Gorse found in this country. The commonest and largest is that known to botanists as *Ulex europaeus* It produces golden yellow flowers in the spring and early summer; and a second crop of blossoms follows in autumn, lasting until nipped by the early frosts. In mild winters the last of the autumn flowers welcomes the first flower of the following spring.

Notice the stiff sharp spine in which each branch ends; the leaf below each branch is often also spiny Remember the general rule that branches arise in the axils of leaves; this will help you to decide which of the outgrowths are branches and which are leaves The branches, like the stem, are cylindrical and furrowed, while the leaves (2 to 5 cms. long) are flat Both the leaves and (in the younger parts of the plant) the branches are green and more or less hairy. If you have a microscope, cut and examine sections of the stem and the branches, and also shavings of the epidermis, and notice that the stomates are found in the furrows; note also the thickness of the cuticle Do you see how these structural features increase the amount of green tissue and so favour photosynthesis, while at the same time the rate of transpiration is kept down?

Why is the Gorse spiny? Two replies have been given to this question It is held by some botanists that spines are the result of an environment of drought and exposure to winds; and it is quite true that Gorse grows most frequently in exposed places, and where the soil is shallow or porous or stony, and hence frequently dry It is also true that many plants which normally occur in deserts are spiny Again, experiments have proved that many spiny plants when grown artificially in a damp atmosphere develop fewer spines or weaker spines, and sometimes no spines at all

A second explanation is that spines are a protection against the attacks of sheep and other browsing animals It is easy to see that spines, when once developed, furnish this protection, but it is difficult to understand how the desirability of being protected against browsing animals should actually cause the spines to be produced in the first instance The correct view is probably that spines are a direct outcome of growth under conditions of exposure and drought, and, once formed, they may have become accentuated because of the protection which they afford

Examine and compare plants found growing in different habitats In moist and sheltered places Gorse is less spiny than usual. By growing a Gorse plant in moist air one gets branches on which there are no spines, and the leaves are broader and thinner than usual It is a fair inference, from these facts, that the hardness and spiny character of the branches, as well as the narrowness of the leaves, are simply adaptations for diminishing transpiration In what "habitats," *i e* in what kinds of locality, does Gorse grow most abundantly? With what other plants is it commonly associated? Do these associate-plants (Broom, Ling, Heaths, etc.) show any adaptations for reducing transpiration?

The two less abundant species of Gorse are smaller in size, and hence are often spoken of as "Dwarf Gorse" One of these (*Ulex Gallii*) is frequent on the hills in the west and north of England, as on the Malverns and the Pennines, also in Ireland The other (*Ulex nanus*) is mainly confined to the south of England, often growing with the Common Gorse, from which it is easily distinguished by the smaller size of the plant and of all its parts The two small species of Gorse are distinguished by the kind of primary spines they bear: in *Ulex nanus* they are weak and short, and in *Ulex Gallii* they are longer and rigid.

The flowers are yellow, slightly scented, about 20 mm long, and are borne on the spines of last year's growth, each flower arising in the axil of a small leaf. The flower has a short stalk, and just below the calyx there are two small oval bracts, one at each side. The calyx is dull yellow, covered outside with short blackish hairs, and divided nearly to the base into an upper lobe and a lower lobe; both lobes are triangular and concave, with pointed tips (the tip of the upper lobe often has 2 small teeth while that of the lower has 3 teeth).

The bright yellow corolla consists of 5 petals which are easily separated from each other; the wings are longer than the keel, and the peg and socket connection between wings and keel is very distinct and easily made out. Both wing-petals and keel-petals are oblong, rounded at the free ends, and have distinct stalks; the keel-petals are joined by the interlocking of hairs which fringe the lower edge of their rounded portions The filaments of the 10 stamens are all joined to form a tube. The stamens usually show a peculiar arrangement, the filaments being long and short alternately; the anthers of the long stamens are attached to the filament by the base, while the anthers of the short stamens are versatile, *i e.* the filament is fixed to the middle of the anther so that the latter can easily be moved about. The ovary is covered with silky hairs; the style is long and curved.

It is interesting to watch bees visiting the newly-opened flower, or to imitate the bee's action by pressing down the keel The flower "explodes", the stamens and style, which are coiled up within the keel, suddenly fly out when the keel is pushed down, so that the bee is dusted with pollen and the stigma also comes against the bee's body. The bursting-open of the flower is due largely to the fact that the keel-petals are pressed together above as well as below by their edges, so that the coiled stamens and style are confined under pressure. The flower can only be properly visited once by a bee; the stamens and style do not go back into the keel, and the wings and keel-petals remain separate.

The pods in all three species of Gorse ripen during the summer only, pods formed from autumn-flowers remain in a resting condition throughout the whole of the winter, Some other autumn-flowering plants, such as the Ivy, have the same peculiarity.

Examine fruits (pods) of different ages, note the blackness and hardness of the ripe pod Why are the two valves of an opened pod twisted?

Have you ever stood beside Gorse-bushes on a warm dry day and heard the curious crackling noise due to the bursting of the pods? It is easy, if you watch carefully, to see the pods bursting and the two valves curling up, so as to fling out the seeds On sunny days in summer ripe pods may be heard bursting with an audible "pop", and the force of the explosion is sufficient to open the two valves of the pod and scatter the seeds a few feet away from the parent plant This scattering of seeds is of course very useful to plants, but the distance to which the seeds are scattered is often exaggerated It is a common idea, for instance, that wind-borne seeds (such as those of the Sycamore) may be scattered for miles, but a few hundred yards is a more correct estimate Do not rest content with reading about the explosive discharge of the seeds in Gorse make observations for yourself

Collect and sow Gorse seeds, or search for the seedlings in the neighbourhood of the bushes The cotyledons come above ground and grow into fairly large oval green leaves What do you notice about the earliest foliage-leaves, which come after the cotyledons? How do they differ from the later leaves? In what members of the Bean family are *all* the foliage-leaves like those of the young Gorse seedling? The young Gorse seedling has no spines: it has two simple seed-leaves, and a number of trifoliate leaves. In the older seedling a gradual transition may be traced from these trifoliate leaves, through simple linear leaves, to mature spiny leaves. The trifoliate leaves of the seedling indicate a relationship with certain other plants with trifoliate leaves, such as Broom, Laburnum, and even Clover.

Grow young Gorse plants in moist air; set the pot of seedlings in a shallow dish containing water and cover with a bell-jar, tilting the latter so as to allow the young plants to have fresh air How do the young plants grown under these conditions differ from plants growing on heaths or in other exposed places or in sandy soil? Make notes (with sketches) of all your observations, adding the inferences you draw as to the adaptations of the Gorse plant to its mode of life

385. Laburnum (*Cytisus laburnum*) is a native of central Europe, it was introduced into England about 1600. It forms a small tree, rarely over twenty feet high.

Note that the spreading main branches bend over and droop at the tips, from the upper side of the bend arise erect long shoots which later also droop, so that the tree has typically a fountain-like habit The bark is very characteristic, it remains smooth for many years, but later on transverse furrows are formed on the trunk and large scales of bark come off Each leaf has a long main stalk carrying three short-stalked pointed leaflets which have entire edges and a silky lower surface; there are long slender stipules which soon wither, but usually do not fall off.

The resting-buds are pointed and covered with silky scales, each usually showing a small three-lobed tip (undeveloped leaflets) Most of the buds grow into dwarf shoots which grow very slowly and bear crowded leaves.

The flowers, which appear in May, are carried in long hanging racemes Each flower is stalked and projects horizontally, the stalk (when the flower is young) twisting round so as to bring the flower into the right position, *i e.* with the keel downwards and the standard upwards The calyx and corolla resemble those of Gorse, and the stamens are all joined by their filaments; the anthers are alternately large and small, the style is long and curved. The flowers are visited chiefly by bees; the nectary is a solid swelling at the base of the standard, on which there are two dark streaks (honey-guides). Note the ring of hairs at the top of the style in the young flower, these hairs prevent the pollen of the flower's own anthers from touching the stigma, but after the style has grown right to the tip of the keel these hairs wither and the stigma is now exposed so as to receive pollen from a visiting bee.

The ripe pod is long, thin, brittle; it contains from three to eight brown or nearly black globular seeds which are poisonous The cotyledons are carried up and turn green; even the earliest foliage-leaves have three leaflets.

Laburnum is closely related to Gorse and to Broom.

386. The Bean Family is one of the largest, and also one of the most useful, among flowering plants. The family as a whole is characterised by the fruit being, with rare exceptions, a pod (legume), whence its name Leguminosae. In the great majority of the species, forming the sub-family **Papilionaceae**, the flower has the same general structure as that of the Broad Bean. There are two other sub-families, not represented in Britain; one of these includes the Acacias and the Sensitive Plant (*Mimosa*). The family includes trees, shrubs, creeping plants, climbing plants, erect herbs, annuals, and perennials, the leaves vary greatly in form, etc. The Papilionaceae are easily recognised by their flowers. Examine all the plants of this type that you find growing wild or in cultivation.

The British Papilionaceae may be divided into five tribes. I. Gorse tribe leaf simple or of 2 or 3 leaflets, no tendrils, leaves (or leaflets) with entire margin. II. Clover tribe like I, but leaflets serrate. III. Lotus tribe leaf with 2 or more pairs of leaflets and an end-leaflet, no tendrils. IV. Sainfoin tribe like III, but pod consisting of 1 or more indehiscent one-seeded joints instead of opening by 2 valves. V. Vetch tribe leaf with the stalk ending in a tendril or point.

387. Gorse Tribe.

A. Calyx deeply 2-lipped, coloured	*Ulex*
B. Calyx shortly 2-lipped, green.	
1. Each calyx-lip deeply toothed .. .	*Genista*
2. Each calyx-lip minutely toothed .. .	*Cytisus*

Broom (*Cytisus scoparius*) grows chiefly on commons and heaths, in sandy or gravelly soil, and is easily recognised by its numerous slender green angular branches and small leaves. The structure of the Broom flower resembles that of Gorse and Laburnum, but the style is longer and is tightly coiled up, as are also the long stamens. The flower "explodes" violently when the keel is pressed down. The mechanism is fairly easy to make out, either by pushing the keel down or, better, by carefully watching what happens when a bee visits the flower.

How is the Broom adapted to its habitat?

Needle Gorse or **Petty Whin** (*Genista anglica*), on heaths, resembles Gorse in being prickly. Note the minute simple leaves, the slender curved spines, and the flowers (May-July).

Dyer's Greenweed (*Genista tinctoria*), in meadows and waste places. It has no spines, and its leaves are larger than in *G. anglica* or in the Broom. It resembles Broom in habit, but never grows so high.

388. Clover Tribe.

A. Stamens monadelphous (all joined)... .. *Ononis*
B. Stamens diadelphous (upper one free)
  1. Flowers in heads, pod straight .. .. .. *Trifolium.*
  2. Flowers in racemes, pod coiled .. .. *Medicago.*

Rest-harrow (*Ononis*), easily recognised, grows chiefly in dry fields and near the sea. It often has spiny branches, leaves with 3 leaflets or only 1 sometimes, toothed, often sticky; flowers (June-Sept.) pink, 20 mm. long, single or in short racemes.

The **Medicks** (*Medicago*) have leaves and flowers rather like those of Clover, but the pod is coiled up and the petals never persist around it. The commoner species are easily distd.

Black Medick (*M. lupulina*) is creeping, with short-stalked leaves, ½-heart-shaped stipule, egg-shaped heads of very small (3 mm. long) yellow flowers (May-Aug.), and small, black, smooth, kidney-shaped, one-seeded pods.

Spotted Medick (*M. maculata*) has larger leaflets, flowers, and pods; the leaflet gen. has a dark central spot, and the pod has many seeds and 3 to 5 coils and bears curved spines.

[**Lucerne** (*M. sativa*), cultd. for fodder, has larger flowers (12 mm. long), gen. blue or purple, in a dense raceme (May-July), pods downy, with 2 or 3 coils.]

389. Lotus Tribe.

A. Calyx shorter than corolla
  1. Pod constricted between seeds .. . ... *Lotus.*
  2. Pod divided by a longitudinal partition ... *Astragalus*
B. Calyx longer than corolla . ... *Anthyllis.*

The common **Bird's-foot Trefoil** (*Lotus corniculatus*), in fields and waste places, has 5 leaflets, but the petiole is very short, so that the 2 lowest leaflets look like stipules, close to the stem, the real stipules being very small; the yellow flrs. (June-Sept.), often with red streaks, are in a spreading head on a long stalk, the head of cylindrical jointed pods rather resembles a bird's foot.

Lady's Fingers (*Anthyllis*), in dry and hilly pastures and by the sea, is erect, with 2 to 6 pairs of leaflets to each leaf, and is clad with silky hairs, especially the flower-heads, which are usually in pairs on a common stalk, head 15 to 40 mm. across, flrs. (June-Aug.) usually yellow.

Milk Vetch (*Astragalus*), also found chiefly in dry and hilly pastures, and is a low straggling plant, leaf of 10 to 12 pairs of leaflets; flrs. (June-Aug.) in racemes or spikes, purple or cream-white.

390 Sainfoin Tribe.

A. Pod cylindrical, many-jointed	*Ornithopus.*
B Pod flat, of several curved joints .	*Hippocrepis*
C Pod hard, one-seeded	*Onobrychis*

Bird's-foot (*Ornithopus*) differs from *Lotus* in having numerous leaflets (6 to 12 pairs); flrs (May-July) white, pod curved, jointed, and beaked, breaking across into one-seeded joints when ripe.

Horseshoe Vetch (*Hippocrepis*), in dry and especially in limestone pastures, has flrs (May-Aug) like *Lotus*, but smaller and paler yellow, 4 to 6 pairs of leaflets, curved pod, breaking into 3 to 6 horseshoe-like joints.

Sainfoin (*Onobrychis*), much grown for fodder, has spikes of pink flrs. (June-Aug).

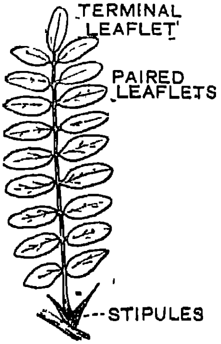

Fig 118 —Leaf of Robinia Pseudacacia with Spiny Stipules

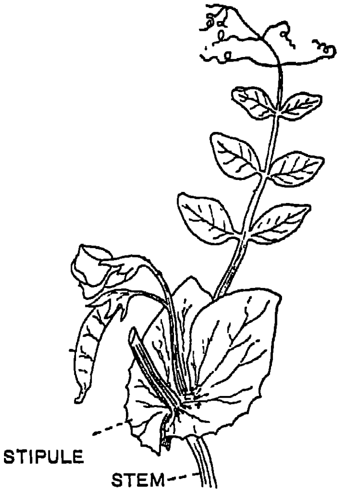

Fig. 110 —Part of a Garden (Eating) Pea Plant (*Pisum sativum*).

391. [**Papilionaceous Trees and Shrubs.**—The following introduced plants are commonly grown. The "**False Acacia**" or "**Locust Tree**" (*Robinia*) is easily recognised (Fig 118) by the pair of spines at the base of the petiole; the evening "sleep" appearance of the large compound leaves, with the numerous paired leaflets all placed vertically face to face, is very striking, flrs (May, June) usually white, in long hanging racemes. *Wistaria*, often grown against walls, is a woody twining plant with compound opposite leaves and hanging racemes of blue flrs , the common Chinese kind (flrs May and June, often with a second crop in Aug) does not set ripe pods in England **Bladder Senna** (*Colutea*), much grown in parks, is a shrub with compound leaves, about 6 yellow flrs. (June-Aug) on short racemes , pod large, reddish, and bladdery]

392 [**Garden Pea.**—Examine the Garden Pea (*Pisum sativum*), noting the large stipules, the tendrils (= upper leaflets), and the structure of the flowers (Figs 119, 120).]

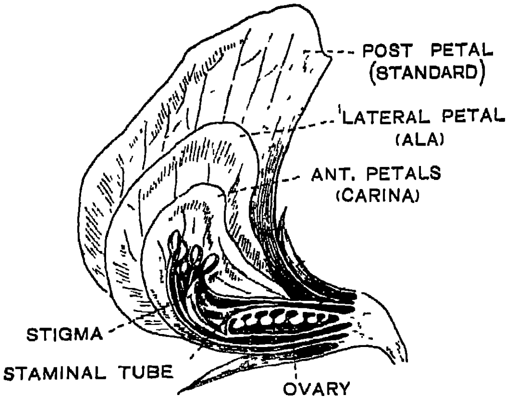

Fig 120.—Median Section, Flower of Garden Pea.
Ala = wing-petal, carina = keel

393 [**Lupin.**—Examine a garden Lupin, noting the curious form of the leaves (long stalk bearing at top a circle of leaflets) The eaflets are covered with bloom and are not wetted by water. Examine the flowers]

394. Flower Mechanisms in Papilionaceae.—In examining the flowers note any differences in the calyx (lobes equal or unequal in length, smooth or hairy, etc), the corolla how are the wings jointed with the keel?); the ten stamens is the stamen joined with the others so as to form a complete stamen-tube, or is it free, and are the filaments equal or unequal in length?); the pistil (length of style, its position with the keel, presence or absence of hairs). In each case ketch all the parts carefully (sketch the separate parts and a longitudinal section of the flower), and find out what happens when the keel is pressed down, if possible, watch bees at work on the flowers. The following notes on the chief types of **flower-mechanism** may be useful —

(*a*) Stamens and stigma emerge from keel when it is depressed, and return inside it again when the bee flies away, the same flower may therefore be visited several times: Clover, Sainfoin, Laburnum, etc

(*b*) Keel-petals joined above as well as below, leaving a small opening at the tip, pollen shed into upper end of keel before flower opens, five of the stamens have filaments thickened below the anthers, and the piston thus formed pushes out some of the pollen each time the keel is depressed · Bird's foot Trefoil (*Lotus*) The other five stamens are shorter and shrivel up after they have shed the pollen, which is carried by the long stamens (those with the thickened ends) into the tip of the keel. A somewhat similar mechanism is found in the Lupin and in Lady's-fingers (*Anthyllis*)

(*c*) Upper edges of keel-petals at first joined, and pollen forced out at tip, as in *b*, but later on the keel splits open, and stamens and stigma emerge as in *a* Rest-harrow (no honey in flower, therefore stamens all united)

(*d*) Like Broad Bean, with tuft of hairs on the style which sweeps the pollen out of the keel when the latter is depressed. most Vetches and Peas

(*e*) Mechanism as in *d*, but stamens long and coiled up within a coiled keel Kidney Bean, Scarlet Runner

(*f*) Stamens and style tightly held, more or less coiled up, in the keel under tension, and springing out violently when keel is depressed Gorse, Broom, Petty Whin (*Genista Anglica*), Dyer's-weed (*G. tinctoria*), Lucerne and other Medicks (*Medicago*)

Recent observations on the flowers of Papilionaceae have led to the generalisation that while many *perennial* kinds have *self-sterile* flowers (see Art 346), *all the self-fertile kinds are annuals.* Some of the latter, in fact, are self-pollinated before the flower-bud opens (*e.g.* Sweet Pea, Garden Pea) The annuals cannot afford to be self-sterile, because they depend on each year's crop of seeds for their very existence, whereas perennial plants can safely run the risk of not being pollinated at all on the chance of securing cross-pollination now and then.

QUESTIONS ON CHAPTER XV.

1. Describe the leaf of a Sweet Pea, with a careful sketch. Why is the stem of the Sweet Pea "winged"?

2. Describe the appearance of (1) a young Sweet Pea tendril before it has met with a support, (2) a tendril which has just caught a support, (3) the same at a later stage, (4) an old tendril which has not grasped any support

3. Describe, from your own observations and experiments, how a tendril acts

4. Describe the vegetative parts (shoot and root) of the Everlasting Pea, and compare it throughout with the ordinary Sweet Pea

5. Describe, with sketches, the flower of a Sweet Pea and its method of pollination.

6. Describe a common Vetch (*Vicia*) and compare it (as to shoot, leaves, flowers) with Sweet Pea and with Broad Bean.

7. Why is the Broad Bean placed with the Vetch (*Vicia*) genus, and not with other "Beans," *e g.* French Bean or Scarlet Runner?

8 Describe the mode of growth of White Clover and compare it with that of Red Clover, pointing out how the vegetative organs of each adapt it to its surroundings

9 Describe the sleep-movements of a Clover leaf as they occur in nature, and explain their causes and their utility Give an account of experiments you have yourself made on these movements.

10 Compare the habit, habitat, leaf-structure, and leaf-movements of Clover and Wood Sorrel.

11 Describe and compare the flowers of Red Clover and White Clover, pointing out any differences in structure and mode of pollination

12. Describe the way in which the Scarlet Runner climbs, and compare its climbing with that of Sweet Pea or Garden Pea.

13 Can you explain why a Scarlet Runner can only climb vertical or inclined supports, while a Sweet Pea can climb round even horizontal supports?

14. Describe the flower-structure and pollination-mechanism of a Scarlet Runner, with sketches.

15. How can you cause a Sweet Pea plant, or a cut branch, to go on flowering for a longer time than it would if left alone?

16. Sketch part of a Gorse plant, marking clearly which structures are leaves and which are stems How are these organs distinguished?

17 Point out the structural features by which a Gorse plant is adapted to its usual habitat. What other plants are often found growing along with Gorse?

18. Describe observations and experiments which show that the peculiar features of the Gorse plant are adaptations for enduring drought.

19 Describe the seedling of Gorse, and discuss its structure and its relation to the structure of the mature plant.

20. Describe the structure of the Gorse flower What happens when a bee alights on the flower? How often can a Gorse flower be visited by bees?

21. Describe the appearance of a Laburnum tree (1) in winter, (2) in spring, (3) in late summer or in autumn.

22 Describe the inflorescence of Laburnum, and compare it with the inflorescences of the other plants of the Bean family which you have studied

23 In what respect does the nutrition of plants of the Bean family differ from that of most flowering-plants?

24 Name eight papilionaceous flowers, of which six must be British. Describe carefully, from observations you have made, the pollination of any one of these and draw its floral diagram

CHAPTER XVI.

THE BUTTERCUP FAMILY

395. Little Celandine (*Ranunculus ficaria*) —This familiar plant, easily recognised by its glossy heart-shaped leaves and its bright-yellow star-like flowers, grows chiefly in moist places, whether open or shaded

Dig up entire plants and notice that there is no tap-root and that some of the roots are long, thin, and branched, while others are short, thick, swollen, and unbranched. Do the swollen roots contain reserve-food? How do the two kinds of roots differ in function? Cut across a swollen root and test with iodine solution is starch present? Look for young shoots early in February, before the flowers have appeared, and note that above the swollen roots the young shoot has given off a number of ordinary roots, the latter serve for absorbing water and salts, while the growth of the shoot takes place at the expense of the food stored in the thick (often club-shaped) *root-tubers* Note the large membranous sheathing scales (how many?) which protect the young shoot Try to find earlier stages, with the young shoot still enclosed in its sheathing scales, before the leaves and the slender roots have grown out; when were the *tuberous* roots formed?

Examine plants in different stages of growth and at different times of the year, keeping some under observation in pots or boxes, and make out as much as possible of their life-history How do the root-tubers change as the leaves grow larger and the flowers appear? Note that the leaves are stalked, arise from the stem in opposite pairs (as a rule), and that the base of the stalk is broad and sheathing.

Examine the flowers (February to May), each on a stalk arising in a leaf-axil In most cases the flower has three green sepals, then an outer series (whorl) of three petals alternating with the sepals, then an inner series of five petals, when there are more than eight petals, the extra petals lie within the normal inner series of five (compare with flower of Buttercup) Each petal has a small scale-like nectary at the base of its inner (upper) surface · why is this surface bright yellow and shiny, while the outer (lower) surface of each petal is dull and dark-coloured?

What difference is observed if you visit the flowers on fine sunny days and on dull or wet days? What advantages does the flower gain by closing in bad weather (wet, cold, or overcast)? In what kind of weather are most insects seen on the wing, visiting flowers? Note the numerous stamens, which ripen successively towards the centre of the flower, and the numerous carpels, which are not ready for pollination (*i e* the stigmas do not become expanded and sticky) until most of the anthers have opened (what is the advantage in this arrangement?) Examine the carpels carefully, noting the small stigma on each Sketch (1) an entire flower, open, (2) the same, closed, (3) a sepal, (4) a petal, (5) a stamen, (6) a carpel, (7) a longitudinal section of the flower.

The flowers are visited by various insects, the pollen being quite accessible and the honey only slightly hidden, so that flies as well as bees and wasps help in pollination. After pollination the flower-stalk curls over while the fruits are ripening What other changes occur in an old flower, after it has been pollinated, or at least has had its chance of pollination? How do the petals change in colour, and why do they lose their power of closing up? It might be suggested that the bleaching of the old petals saves the time of intelligent insects, *e.g* bees, by showing them that the flower is no longer worth visiting.

The fruits (akenes, nearly globular) are ripe about June Examine an akene, peel off the coat, cut sections, and note the small embryo at one end of the seed, the bulk of which is occupied by endosperm, the embryo is peculiar in having only one cotyledon instead of two. Sow ripe seeds and study the seedlings, they take rather a long time to germinate

You will generally find that plants growing in deeply shaded places—in woods or under dense hedges—produce few fruits (why?), but to atone for this the plants produce small tuberous bodies (bulbils) in the axils of the leaves (note that shaded plants have longer stems and are less compact than those growing well exposed to light) Each bulbil contains starch and has a resting-bud, the bulbils eventually become detached and give rise to new plants. The shoots die down soon after the fruits have ripened, food being stored for the following spring in the tuberous roots and the bulbils, which are "hibernating" organs.

396. Buttercups (Fig. 121) belong to the same genus (*Ranunculus*) as the Little Celandine. They differ from it in having lobed (often deeply divided) leaves, five sepals, and five petals.

In a Buttercup flower note the five green sepals; the five petals alternating with these, each with a honey-scale at the base, the numerous stamens, the numerous carpels, each having a small thickened or hook-like stigma. Each of these parts is inserted independently on the receptacle, which is merely the expanded knob-like end of the flower-stalk. There is no *cohesion—i e* the receptacle-tissue does not grow up and raise the members of a series of flower-leaves on a basal outgrowth (compare sepals and stamens of Bean), the carpels contain each a single ovule, attached to the bottom of the ovary.

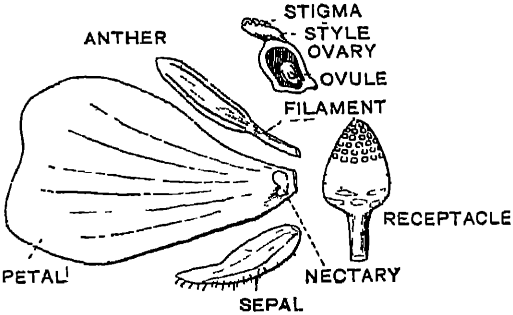

Fig 121 —The Parts of a Buttercup Flower
The points of insertion of the different parts are diagrammatically represented on the receptacle

The flower is shallow, accessible to all kinds of insects, which visit it for the abundant pollen as well as for the honey (only slightly concealed by the outer stamens). Examine flowers of different ages; the outer stamens have shed their pollen (the anthers open at the sides), while the inner ones are still bent over the carpels, covering the stigmas, which are not exposed until most of the stamens have moved outwards and have set the pollen free to be carried away by insects. The "male stage" and the "female stage" thus overlap for some time, during which self-pollination is possible, either because the innermost stamens touch the stigmas or by means of small insects crawling over the flowers.

397. The **Bulbous Buttercup** (*R. bulbosus*) is easily distinguished when in flower; the sepals curve outwards and downwards. The stem is swollen at the base, forming a kind of corm; the lower leaves are broad and many-lobed, the upper ones have only a few narrow lobes. The **Creeping Buttercup** (*R. repens*) has long creeping branches (runners) which grow along the soil and at the "nodes" send roots downwards and shoots upwards. The **Meadow Buttercup** (*R. acris*) has neither runners nor a thickened stem-base, its flower-stalks are not grooved (as are those of the other two species), and it is the tallest of British Buttercups, being sometimes more than a yard in height; the sepals are, like those of *R. repens*, spreading, not reflexed as in *R. bulbosus*.

R. bulbosus flowers chiefly in early summer (May-July); *R. repens* from May to September; *R. acris* from April to November (all the year round in sheltered places).

The three commonest species of Buttercup agree in many respects—*e.g.* in having five sepals and five petals, etc.—but are distinguished by the following, amongst other, characters:—

	Bulbous Buttercup (*Ranunculus bulbosus*)	Meadow Buttercup (*Ranunculus acris*)	Creeping Buttercup (*Ranunculus repens*)
Stem	Swollen at base, for storage of food	Not swollen at base, no runners	Gives off runners, which root at nodes, producing new plants
Flower-stalk	Furrowed	Not furrowed	Furrowed
Sepals	Reflexed, *i.e.* bent downwards	Spreading	Spreading

The **Celery-leaved Buttercup** (*R sceleratus*) is not so abundant, though found widely distributed It is a more decidedly moisture loving plant than the other Buttercups (given above), growing chiefly in ditches, and it is annual. The lower leaves are stalked and divided into 3 broad shiny hairless toothed lobes, the upper sessile with 3 narrow lobes It differs from the three commonest species in having no scale on the nectary at the base of the petals, and its akenes are raised on an oblong receptacle (owing to growth of the latter after fertilisation) The flowers (June-Sept) are small (5 mm), with pale yellow petals, hardly longer than the sepals which are reflected as in *R. bulbosus*

Goldilocks (*R auricomus*), in woods, is like *R acris* but is less hairy and not so tall, and lower leaves have fewer, shallower, and blunter lobes , its flowers (March-May) often have, instead of the 5 normal petals, numerous imperfect ones passing gradually into stamens, and there is no scale over the nectar-pit

Of the remaining Buttercups, the commoner species are **Pale Hairy B.** (*R hirsutus*), chiefly in cultd fields, with leaves and calyx as in *R bulbosus*, but flowers (June-Sept) more numerous and paler yellow, style straight, akenes very flat and warty at edge ; **Corn B.** (*R arvensis*), a troublesome cornfield weed, with tall (1 to 2 ft.) stem, growing with the corn and ripening its fruits at harvest-time, the flowers (May-July) small (12 mm across) and pale yellow, akenes few but large, covered with hooked spines, the style also forming a stout hook What are the advantages to the Corn Buttercup of (1) the *unbranched* stem, (2) the *hooked* akenes ? These two species are annuals ; *R hirsutus* is rare in Scotland and not found in Ireland, while *R arvensis* is very rare in Ireland

The ordinary Buttercups are sometimes called "Crowfoots" from the shape of the leaves in most species, but the two "Spearworts," which grow in marshy places, are easily distinguished by their long and narrow tapering leaves Like ordinary Buttercups they have yellow flowers The **Lesser Spearwort** (*R flammula*) is the more widely distributed in wet places, marshes, bogs, etc ; it is rarely over 1 foot high, its lower leaves are stalked, and its flowers (June-Aug) about 1 cm in diameter The **Greater Spearwort** (*R lingua*) is 2 to 3 feet high, its leaves are all sessile, and its flowers (July-Sept.) about 4 cms in diameter ; it is not nearly so common.

398. Water Crowfoot (Fig 122) —Under this name are comprised various forms of Buttercup or Crowfoot which live in marshes or streams and have white flowers

The Water Crowfoots are very variable and the varieties are connected by intermediate forms, so that systematic botanists are not agreed as to the number of species that can be distinguished.

(1) Those which grow in fast streams have most or all of their leaves submerged and divided into numerous fine threads

—the form best adapted to resist tearing by the running water, besides increasing the surface for absorption of water with dissolved salts and gases.

(2) In those forms which grow in slow streams, ditches, or ponds, there are usually floating leaves (on the surface of the water) as well as submerged leaves. The former are rounded or lobed, not much divided, and bear stomates on their upper surface. The submerged leaves are finely cut, with numerous segments spreading in a circle.

(3) In forms which grow in shallow streams or pools, in marshes and muddy places, all or most of the leaves are of the entire, rounded or lobed, "floating" type.

We thus get every transition from plants with all or most of the leaves submerged and dissected, to plants with all the leaves broad and either floating on the water or raised above it. The intermediate forms are "amphibious"; when the stream or pond dries up, they grow quite well in the mud, bearing only aerial leaves and no finely divided ones. On the other hand, if flooded or transplanted into water in an aquarium, they will grow and produce only the divided submerged leaves. Experiments of this kind should be made: sow in damp soil the seeds of submerged forms, sow in water those of mud-inhabiting forms.

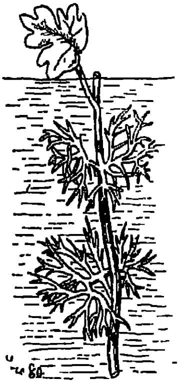

Fig 122.—Part of a Water Crowfoot, showing a floating leaf and two submerged leaves.

In all cases the flowers are carried above the surface of the water; they resemble the flowers of ordinary Buttercups in general structure. The flower-buds are developed below the surface, but do not open until they reach the air.

Some botanists distinguish nearly 20 British species of Water Crowfoot, but they are probably all varieties of one species (*R. aquatilis*). The commonest form has the lower leaves submerged and finely cut and the upper ones floating with broad lobes. The commonest mud-inhabiting form is often called Ivy-leaved Crowfoot (*R. hederaceus*); it has no submerged leaves, its stems root at nearly every node, and the flrs. are very small, the petals being scarcely longer than the sepals; two others are often regarded as distinct species—*R. tripartitus*, with

3-lobed leaves and long narrow 3-veined petals, and *R. lenormandi*, wit kidney-shaped leaves and longer 5-veined petals.

Examine Water Crowfoots, sketching the leaves and flowers Com pare the forms of the leaves in plants growing in fast streams, i ditches, in deep water, in shallow water, in mud, etc Try to accoun for the differences and to find out how they are connected with th different habitats of the plants.

The Water Crowfoots serve admirably to illustrate many points i the biology of aquatic plants (see chapter on Ecology)

399. Marsh Marigold or **Kingcup** (*Caltha palustris*).– This plant, which grows in low-lying meadows, marshe banks of streams, ponds, ditches, and other wet places, has tufted habit.

The thick perennial rhizome bears annual shoots, about foot long, which either grow erect or creep and root a intervals. Most of the leaves arise from the base of th stem and are long-stalked, the sheathing leaf-base has larg membranous stipules which enclose the young buds. Th upper leaves, carried on the flowering branches, are smalle than the lower ("radical") leaves and have very short stalk Cut across stems and leaf-stalks, noting their hollow struc ture. Blow through a leaf, with (1) the stalk, (2) the blad dipping into water, plunge a leaf into hot water.

Note the large flowers (often 2 inches in diameter), wit golden-yellow flower-leaves (*sepals*),[1] numerous stamens, an from 5 to 10 carpels Note the resemblance of each carp to the single carpel ("pistil") of Bean or Gorse. Open u a carpel and note the arrangement of the seeds · how man rows are there, and on what side of the carpel, inner (toward centre of flower) or outer, are they carried? When ripe i becomes a dry fruit (follicle) which splits open along th seed-bearing inner edge, the seeds are gradually shaken ou as the wind rocks the fruit to and fro.

400. The Buttercup Family (Ranunculaceae) is dis tinguished by the complete absence of cohesion or adhesio between the parts of the flower; the sepals, petals, stamen and carpels are always free [except in Nigella, where the carpels are joined together and the fruit is a capsule]. The stamens are indefinite in number, *i.e.* they are numerous and bear no definite numerical relation to the petals or sepals.

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[1] How do these apparent petals differ from the petals of Celandir and Buttercup? Honey is produced at the bases of the carpels; th flowers are visited by beetles (chiefly *Meligethes*, Art. 349), flie bees, etc

The only really common genera in Britain are Ranunculus, Anemone, Clematis, and Caltha, but many are cultivated in gardens for their showy flowers.

I. Fruit a collection of akenes.	
A. Shrubs, with opposite leaves	*Clematis.*
B. Herbs, with (usually) alternate leaves.	
1. Sepals petaloid, no petals.	
(*a*) A ring of bracts below flower	*Anemone*
(*b*) No bracts	*Thalictrum*
2. Sepals and petals present	
(*a*) Sepals green, petals with nectaries	*Ranunculus*
(*b*) Sepals petaloid, no nectaries	[*Adonis*]
II. Fruit a collection of follicles	
A. Flower "regular"	
1. Sepals persist in fruit	*Helleborus.*
2. Sepals fall off	
(*a*) Petals absent	*Caltha*
(*b*) Petals small, entire	*Trollius*
(*c*) Petals small, 2-lipped	[*Eranthis*]
(*d*) Petals large, spurred	*Aquilegia*
B. Flower zygomorphic	
1. Uppermost sepal hooded	*Aconitum.*
2. Uppermost sepal spurred	*Delphinium.*
III. Fruit a berry ...	*Actaea*
IV. Fruit a capsule	[*Nigella*].

401. *Clematis* (**Traveller's Joy, Old Man's Beard**) is the only shrub in the order; it grows in hedges, chiefly on limestone, climbing by its petioles, which are sensitive on the lower side and after turning once round a support turn woody and persist; leaves opposite, of 3 to 5 leaflets; flrs. (July, August) have 4 greenish-white sepals and numerous stamens and carpels; akene with a long (2 to 4 cms.) plume (= persistent style).

Many species of Clematis are cultd., some with large brightly-coloured flrs., and some having the flr. more or less tubular by bases of sepals being erect.

[*Atragene* (*Clematis*) *alpina* has the outer sta. converted into petaloid staminodes.]

402. **Wood Anemone** (*Anemone nemorosa*), very common, has a thin rhizome giving off long-stalked leaves with 3 lobed leaflets, and solitary long-stalked flrs (April, May) with a ring (involucre) of 3 leaves (bracts) below the flr., which has 6 (5 to 9) white or pink sepals and numerous sta. and cpls.

In **Pasque Flower** (*A. pulsatilla*), on limestone downs, the flrs (May, June) are purple and tubular, with honeyed staminodes within the sepals, the style becomes long and feathery (as in *Clematis*), and the 3 bracts are many-lobed.

In the cultd. "Hepatica" Anemone the flrs. (usually blue, March, April) have 3 undivided bracts just below the sepals, and therefore resembling a calyx.

Examine also the cultd. many-coloured Poppy-like Anemones (spring, early summer) and the white Japanese Anemone (Aug.-Oct.) of gardens.

403. **Meadow Rue** (*Thalictrum*) has comp. leaves, often like Maiden-hair Fern, flrs. (June-August) in crowded infls., small, with 4 or 5 small sepals, which soon fall off, yellow or green in the 3 Brit. species, but with pink anthers in some cultd. forms; sta. erect, forming the conspicuous part of the flr., cpls. few.

404. **Pheasant's Eye** (*Adonis*) has globular flrs. with 5 yellow sepals, the petals, which have no nectary, are large and yellow (*A. vernalis*, etc.), or red with a black basal spot (*A. autumnalis*, the one found in Brit., but a garden escape), numerous sta. and cpls.

405. For **Helleborus** examine a cultd. "Christmas Rose" or "Lenten Rose," noting the rhizome, often black, which gives off aerial shoots ending usually in a single flower or bearing a few flowers, and giving off (below surface of soil) the stalked comp. leaves, the flower (Nov.-March) is inclined on its stalk, 5 to 7 cms. diam., and consists of 5 or 6 large sepals (white or pink with green base, persisting and turning green in fruit), 13 (range 10 to 21) stalked green 2-lipped slipper-shaped nectaries, about 90 stamens (in radiating lines, one line starting from each nectary), 5 (sometimes 6 to 10) carpels more or less joined at base.

There are two wild **Hellebores** in Brit. on limestone in S. and E. Eng.—the Setterwort (*H. foetidus*, perennial, aerial stems with numerous drooping flowers, Jan.-April, 25 mm. across, sepals green edged with brown and not spreading until nectaries and sta. have fallen) and Bearsfoot (*H. viridis*, annual; flrs few, inclined, March-April, 40 to 50 cms. across, sepals spreading), both have 3 cpls.

406. [**Winter Aconite** (*Eranthis*) has a tuberous rhizome, "radical" leaves, each with a circle of 3 to 5 lobed leaflets; flrs (Jan.-March) solitary, with an involucre of 2 or 3 lobed leaves, 5-9 (gen. 6) yellow sepals which close up at night and in bad weather, 5-9 (gen. 6) tubular nectaries alt. with sepals, about 30 sta., 3-11 (gen. 6) cpls.]

407 Globe Flower (*Trollius*), rare wild (on hills), but often cultd., has globular flrs (May-August), gen. yellow, with 5 to 15 petaloid sepals, 5 to 15 smaller petals, with nectary pit at base, numerous short sta., 5 or more cpls.

408. [**Paeony.** Note the tuberous roots and the large flrs (May, June) which close at night, sepals 5, passing gradually outwards into the foliage-leaves, 5 or more petals without nectaries, numerous sta., and few (often 2 or 3) large fleshy cpls., joined at base, honey produced abundantly by a disc around the cpls., in some species the fl. has a *tubular* disc.]

409 Examine the **Columbine** (*Aquilegia*), often cultd. in many species and varieties with variously coloured flrs.; *A. vulgaris*, chiefly on limestone, has deep blue flrs (May-July); flrs 1 to 2 ins. across, drooping (but erect in fruit), 5 petaloid sepals, 5 petals with long basal honey-spurs (gen. hooked at end), many sta. in regular series, cpls 5 or more, inner sta. gen. antherless.

410. [*Nigella* (Love-in-a-mist, Devil-in-the-bush), annual, with finely divided leaves. The fl., gen. blue, has an involucre of 5 leaves, 5 petaloid sepals, 5 to 8 pocket-like nectaries each with a lid, 5 cpls with *united* ovaries which split along the partitions when ripe.]

411 The British species of *Actaea* (**Baneberry**), *A. spicata*, grows chiefly in N. Eng. on limestone, but several varieties are cultd. *A. spicata* has small (5 mm. across) white flrs (May) in short dense racemes, sepals 3 to 5, petaloid, soon falling, petals small (4 to 10) or absent, 1 cpl., becoming a black egg-shaped (10 mm. long) many-seeded berry (poisonous).

412. Monkshood (*Aconitum*), not common in Brit., but much cultd. in gardens, has a black rhizome (gen. spindle-shaped and radish-like, but very poisonous), flrs (June-Sept.) blue, etc., with 5 petaloid sepals, the uppermost one forming a large hood, the lowest pair small, petals repd. by 2 long-stalked curious nectaries under the sepal-hood, the other 3 small or absent, filaments of sta. broad at base; cpls 3 to 5.

413 Larkspur (*Delphinium*) is also chiefly known by the garden forms; flrs (June-Aug.) blue, etc., with 5 petaloid sepals, the uppermost having a long basal spur, 2 upper petals, small, each with a spur, the two spurs projecting into the sepal-spur and being pressed together so as to form a tube above and a solid mass (nectary) below, the lowest petal is gen. absent, but the other two (also absent in *D. ajacis*) are brightly coloured and hairy, standing at each side of the entrance to the sepal-spur; cpls. 3 to 5, often reduced to 1, the flr. is at first horizontal but becomes erect in fruit.

414. Flower Mechanisms in Ranunculaceae.—This family shows a wide and interesting range in flower structure, and includes some of the most beautiful examples of adaptation to visits of particular insects The perianth is generally petaloid and rarely shows a "typical" calyx and corolla, though this does occur in the largest genus (the one with most species)—*Ranunculus* In nearly all cases the "petals" either bear nectaries or are represented by more or less elaborate honey-organs These nectaries, which so often occur between the perianth leaves and the stamens, are commonly regarded as modified petals, but more probably they have been derived from the outer stamens and have never been petals at all

Which genera have flowers whose structure seems to suggest (1) that the flower has not yet developed petals, whose attractive function is assumed by the coloured (petaloid) sepals, or (2) that petals may have been derived from the outermost stamens, or (3) that sepals may have evolved from foliage-leaves or bracts growing just below the flower? Perhaps the flowers of this family are still in course of evolution; at any rate, very few show the distinct sepals and petals of a "typical flower" "Sepals" are always present (primarily as a green protective envelope), and should the "petals" develop as honey-tubes or remain undeveloped the "sepals" usually become white or coloured when the flower opens, rarely remaining green (Wild Hellebore), so that it is at least convenient to limit the term "petals" in this family to the honey-leaves.

The flowers are usually protandrous, with the anthers extrorse (opening on their outer faces), but those of *Thalictrum*, *Helleborus*, and *Eranthis* are protogynous, and those of Wood Anemone and *Trollius* are homogamous

Wood Anemone and Traveller's Joy are honeyless flowers, visited chiefly by small insects (flies, etc) for pollen, but in some species of *Anemone* and *Clematis* there are honeyed staminodes partially concealed by the sepal-bases and the stamens, and therefore only reached by fairly long-tongued insects *Adonis* and *Thalictrum* are also "pollen-flowers"; some species of *Thalictrum* have *polygamous* flowers (some with stamens or with carpels only, others with both, on same plant) and are largely wind-pollinated, though the kinds with pretty anthers are visited by insects.

The flowers of *Trollius* and Wood Anemone are often self-pollinated, and in most of the other genera self-pollination may occur as a last resort, but in *Helleborus* it is precluded by the absolute protogyny of the flower. In *Nigella* the long styles are at first erect, out of reach of the stamens (the flower is protogynous), but before all the anthers have opened the styles (unless already pollinated) bend down and thus bring about self-pollination.

Eranthis and Paeony show closing movements to protect the pollen and honey (cf. Little Celandine), and *Trollius* has the flowers nearly closed all the time; similar protection is given by the inclined or drooping position of the flower in *Helleborus* and in *Aquilegia* (the hooked end of the petal-spurs prevents the honey from dropping out), by the arched hood in Monkshood, and the horizontal position of the flower in Larkspur. The nectaries of Columbine, Larkspur, and Monkshood can only be reached by long-tongued bees; the flowers open in summer, when bees are plentiful, are visited chiefly by humble-bees, and usually have the rich blue colour characteristic of so many "bee-flowers."

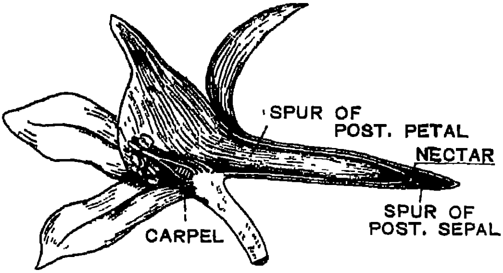


Fig. 123.—Longitudinal Section of Flower of Larkspur (*D. ajacis*).

The flowers of Larkspur (Fig. 123) and Monkshood (Fig. 124) are the most highly specialised in the family, and the visiting insects can only enter in one particular way to reach the well-concealed nectaries; the stamens move upwards or inwards in turn, as they ripen, so as to block the way to the nectaries, each stamen moving away again when its pollen is shed. In Larkspur the entrance to the spur is further narrowed by the two side-petals, present in most species, which also act as "honey-guides"

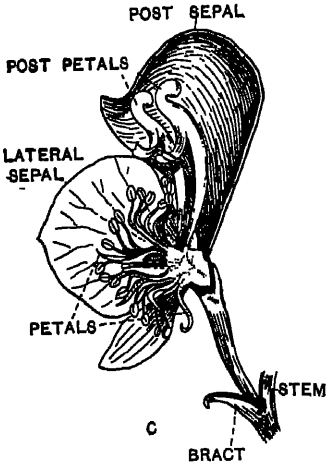


Fig 124 —Longitudinal Section of Flower of Monkshood

The humble-bee often bites through the petal-spurs of Columbine and the hood-sepal of Monkshood, but the thick double-walled spur of Larkspur seems to prevent this. These three flowers are fine examples of adaptation to a special insect-visitor, the pollen and honey are sheltered from rain, and the honey can only be reached by a large and long-tongued bee All three flower in midsummer, when humble-bees are most abundant The limit of distribution of the Monkshoods (*Aconitum*) over the earth closely follows, and is just within, that of the humble-bee (*Bombus*)

415. Classification (Varieties, Species, Genera, Orders, Cohorts).—The study of the Buttercup family affords a good opportunity to learn something of the principles involved in the classification of plants The object of classification is to arrange plants in a scheme which shall as nearly as possible express their actual affinities or relationships by descent, *i e* by evolution from common ancestors A really natural scheme of classification can never be more than an expression of our views concerning these "blood relationships," but as our knowledge increases by further research the system becomes more and more a true reflection of the affinities of plants

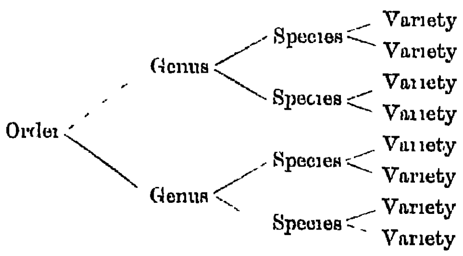
As is well known, there is a certain amount of variation among the offspring of all plants, though the general characters of the parents are handed down by heredity. Sometimes the variations are slight and "continuous," *i e* connected by intermediate forms with one another, but they may be more marked and "discontinuous," *i e.* hardly, if at all, connected in this way Formerly it was believed that the small continuous variations formed the material from which species arose by natural selection, but there is reason to regard the large discontinuous variations or "mutations" as being of much greater importance in evolution

When variations are very marked as well as "discontinuous," they become more or less fixed **varieties**. For instance, there are two common varieties of Meadow Buttercup (*Ranunculus acris*): in one the stem is densely hairy at the base, and the segments of the "radical" leaves overlap each other; in the other variety the stem is only slightly hairy, and the leaf-segments do not overlap. Many examples of varieties are found in cultivated plants. Varieties differ from each other in small and variable characters, chiefly affecting the vegetative organs, but sometimes in floral characters of slight importance—e.g. shape and colour of petals. **Species** differ in more important characters of the vegetative organs, or of flowers and fruits, or of both. We have already studied the distinguishing characters of the commoner species of Buttercup. When the differences become still more pronounced and more constant we agree to recognise distinct **genera**, and a number of closely related genera constitute a **Natural Order.** Thus the Buttercups, Anemones, Marsh Marigolds, Aconites, Larkspurs, etc., all belong to different genera of the Natural Order **Ranunculaceae.**

Natural Orders differ from one another in having different types of flowers and different arrangements of the flowers and leaves. Families or orders are grouped into **Cohorts.** The cohort **Ranales** includes, besides the Ranunculaceae, the Nymphaeaceae (Water-lily order), Magnoliaceae (Tulip-tree order), Berberidaceae (Barberry order), Myristicaceae (Nutmeg order), Lauraceae (Laurel order), and a few others. The cohorts of seed-plants fall into four great divisions—**Gymnosperms, Monocotyledons, Lower Dicotyledons** (*Archichlamydeae*), and **Higher Dicotyledons** (*Sympetalae*)—the three latter divisions forming the **Angiosperms.**

As you proceed with the work of classifying plants, you will realise that the boundaries between varieties and species, between species and genera, and so on, cannot be precisely and sharply defined; the same applies even to the boundary between the lowest plants and animals. This is, of course, just what we might expect from what we know about variation and evolution. Hence an absolutely natural system of classification can only be an ideal to be aimed at.

The relations between a variety, a species, a genus, and an order may be shown as below —



Of course, there are many species which, though variable (as all species are), have no distinct varieties—that is, they show continuous but not discontinuous variation. A species may have many or few varieties, a genus many or few species, and an order many or few genera. In fact some genera have only one species—that is, a species may be so distinct from other plants that it is raised to the rank of a genus. And a single genus may be regarded as forming an order by itself—there are several such cases known. In the scheme given above, each species is represented as having two varieties, each genus as having two species, and the order as consisting of two genera.

QUESTIONS ON CHAPTER XVI

1 How does the Little Celandine hibernate, and at the same time multiply apart from seed-production?

2 Describe, with sketch, the appearance of a Little Celandine plant when its leaves first appear (end of January or in February).

3 Describe the flower of Little Celandine and compare it with that of an ordinary Buttercup. What property has the Celandine flower that is not possessed by a Buttercup flower, and why?

4 Describe, from your own observations, the movements shown by the flower and the flower-stalk of Little Celandine.

5 Name the three commonest English species of Buttercup. Describe any one of them as fully as possible, and point out exactly the characters in which the other two differ from it and from one another. How do they differ as regards the situations in which they usually grow, and the time of year in which they flower most freely?

6 Describe the adaptations which the flowers of Celandine, Buttercups, and Water Crowfoot have for securing pollination. Which of these will be likely to receive most insect-visits, and why? Which will get fewest visitors, and why?

7 Describe a Water Crowfoot and compare it with an ordinary Buttercup.

8 Describe the adaptations shown by a water plant, with floating leaves or submerged leaves or both kinds, to its mode of life.

9 Why are aquatic Flowering Plants believed to have descended from land plants?

10 Describe and compare the leaves, flowers, fruits, and mode of life of Marsh Marigold and Little Celandine. Why are the yellow leaves of the flower of Marsh Marigold regarded as being sepals and not petals?

11 Describe the flowers and fruits of Clematis, and point out the resemblances and differences between this plant and a Buttercup By what organs does Clematis climb? In what respects does Clematis differ from the other British members of the Buttercup family?

12. Describe the flowers of Larkspur and Monkshood, and compare them with a Buttercup flower

13 Distinguish between a species, a variety, a natural order, and a genus, illustrating your answer by reference to three examples of each Can you exhibit the relations of the four in a diagrammatic form?

14 Describe, with drawings, the appearance and structure (not microscopical) of the fruits of five different members of the Ranunculaceae, and also of any five of the following seeds Maize, Bean, Almond, Castor Oil, Pine, Sunflower, Gourd

CHAPTER XVII.

THE ROSE FAMILY.

416. Dog Rose (*Rosa canina*)—There are many species and varieties of Wild Roses in Britain, the Dog Rose being the commonest

The plant has a woody "stock" which produces suckers, these are also given off by the roots in some cases During the first year of growth each shoot usually grows erect to a height of three or four feet and does not branch; later on the shoot may branch freely and reach a length of ten feet or more in a single season

How do the long arched shoots scramble over other plants in a hedge? Try to pull a branch away from the hedge note how it resists your pull by clinging to its companion plants in the hedgerow Sketch a piece of the shoot, showing the shape of the prickles and the direction in which they curve Are the prickles deeply embedded in the stem, or can they be pushed off easily? Each prickle is evidently part of the rind or outer tissue of the stem Are the prickles scattered evenly over the branch, or do they tend to be clustered at the "nodes" where the leaves come off? Do you see any advantage in this arrangement of the prickles?

How many leaflets are there on each leaf? Does the leaf bear any prickles? Sketch a leaf, showing the narrow pointed stipules which adhere to the base of the leaf-stalk, pull a leaf down and notice the bud, which is protected by the stipules

Trace a side shoot down from its tip to the place where it springs from an older, leafless part, note the leaf-scars on this older part, which belongs to last year's growth Trace this two-year-old part back to where it in turn arises from an older stem with a darker surface, this three-year-old part is thicker and harder to cut

Do all the shoots bear flowers? Do the flowers grow singly or in clusters? Are the flowers found in the thick parts of the hedge, or only at the top and along the sides, where there is plenty of air and sunlight? How does the arrangement seem advantageous with regard to (1) the pollination of the flowers, (2) the ripening of the fruits, (3) the dispersal of the fruits?

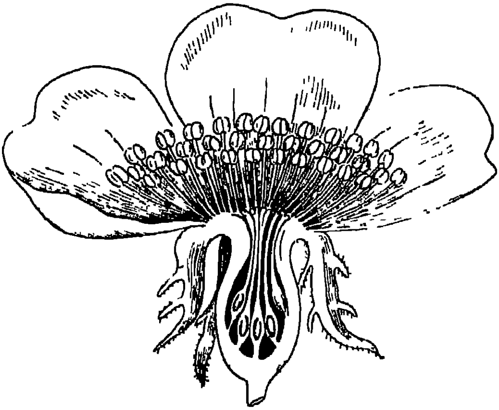


Fig 125 —Longitudinal Section of Flower of Dog Rose

Examine a flower (Fig 125), noting the green urn-like tube from the edge of which arise the five green sepals, the five white or reddish petals, and the numerous stamens; the petals are attached by a narrow base, as in Buttercups, while the sepals have broad bases Examine the sepals carefully, noting the appendages which fringe the edges; are all the sepals fringed on *both* sides, or are any of them fringed on one side only, or not fringed at all? Examine a flower-bud and see whether the relative positions of the sepals throw light on the distribution of the fringes

The Dog Rose has no honey, but the flowers (June to August) are visited by various insects for pollen Note the numerous styles, each with a slightly dilated stigma, which project a little from the mouth of the flower-tube. Cut a flower down through the middle of the tube and trace the styles down to the ovaries which are inserted all over the lower part of the tube The stigmas become receptive practically at the same time that the anthers open, but insects generally alight on the stigmas first, and thus bring to them pollen from previously visited flowers.

Examine twigs showing various stages in the formation of the fruits ("hips"), noting that the sepals become bent downwards but do not fall off before the fruit ripens and turns red Note the shape of the fruit (from what part of the flower is the red fleshy "hip" formed?), the narrow mouth of which is blocked with woolly material, on the rim of the urn notice the five scars where the sepals have fallen Cut the "hip" in two longitudinally, noting its thick wall and the numerous seed-like bodies (really fruits, *akenes*, since each is formed from an ovary) within it, and the white threads (bundles) passing from the flower-stalk into the wall of the "hip" Why is one side of each akene curved and the other two sides flat? Note the slender thread (style) at the top of each akene, also the stiff brittle hairs covering the akenes and the inner surface of the "hip" The akenes are dispersed by birds, which are attracted by the bright colour of the fleshy "hip"

Some of the commoner Wild Roses are easily identified. The **Burnet Rose** or **Scotch Rose** (*R spinosissima*) is a small erect bushy plant (1 to 3 ft high), chiefly found on sand or shingle at the coast, with crowded prickles varying in size and shape, but mostly straight, and passing into mere bristles and glandular hairs, seven to nine small leaflets, flowers small, solitary, fruit nearly black, sepals persistent and erect on top of "hip" The **Sweet Briar** (*R rubiginosa*) is more closely allied to Dog Rose, but its leaves have a pleasant smell when rubbed owing to an aromatic substance produced by numerous small reddish gland hairs on leaf-stalks and lower side of leaflets; the prickles are hooked but mixed with bristles and hairs, flowers usually solitary The **Field Rose** (*R arvensis*) has leaves and prickles as in Dog Rose, but is a more trailing plant, the flowers are white, scentless, in clusters (3 or 4), "hip" globular; sepals not fringed, styles united into a column which projects from mouth of "hip", this species keeps on flowering later than the Dog Rose The **Downy Rose** (*R villosa*) is distinguished from the downy varieties of Dog Rose by the globular fruit, which bears small prickles, the stem-prickles are straight or only slightly curved, the leaflets downy on both sides

417. Strawberry (*Fragaria vesca*) —The cultivated kinds should be examined as well as the wild form, which differs chiefly in the smaller size of the various parts

Note the perennial rhizome, which is woody and scaly, giving off in early summer the numerous creeping branches (runners) Each runner arises in the axil of a leaf on the rhizome, grows along the soil, and at intervals sends roots downwards and shoots upwards The roots contract and become wrinkled, pulling into the soil the shoots, from whose bases more roots grow out The flowering shoots are erect (3 to 6 ins), covered with soft hairs; the basal leaves have long stalks with three leaflets with toothed edges, but the upper leaves are simpler and have short stalks or none

The runners of the Strawberry not only enable the plant to spread over the soil and send up leafy and flowering shoots where there is plenty of air and light, they also serve for propagation apart from seeds, that is, "vegetative" reproduction, since the slender scale-bearing part of the runner withers after the new shoots have grown up, the latter become free from the parent and form independent plants

In the flowers note first the saucer-like receptacle (corresponding to the urn-like structure in the Rose flower) bearing at its edge five green sepals, on its upper side the five white petals and the numerous stamens, and on its lower side five small green leaves alternating with the sepals The leaves below the sepals form the "epicalyx", they represent the stipules of the sepals, which have grown together in pairs In the centre of the flower arises a knob which bears the numerous small carpels, each with a short style and a small stigma, between the rim of the "saucer" and the central carpel-bearing knob there is a ring-like nectary

The honey is only slightly concealed by the stamens, and the flowers are visited by flies as well as by larger and longer-tongued insects (bees, etc) The stigmas become ready to receive pollen, *i e* reach their full size and become sticky, before the anthers of the flower open to shed the pollen, so that self-pollination is to some extent hindered and cross-pollination favoured, pollen may be brought to the flower in its first ("female") stage from another flower (younger or older?) In some cultivated varieties of Strawberry the lower part of the knob bears no carpels, and sometimes the flowers are unisexual, *i e* either have stamens or carpels, but not both in the same flower

After fertilisation of the carpels, the central knob swells and becomes fleshy, the petals fall off, but all the other parts persist, even the withered stamens The ripe carpels or "pips" (akenes) remain on the surface of the knob and are dispersed by birds which are attracted by the brightly coloured and fleshy mass, eat it and the "pips," and either drop the latter or pass them through their digestive canal

Compare the fruits of Strawberry and Rose In the Strawberry the receptacle is divided into a saucer-like part and a central knob, instead of being a deep urn with a narrow mouth, and the akenes are borne on the surface of the knob instead of being on the inside of a cup In both cases, however, the fleshy part is formed from the receptacle, and it is instrumental in bringing about the dispersal of the akenes by birds

Be careful not to confuse the true Wild Strawberry with the "**Strawberry-leaved Potentil,**" often also called "**Barren Strawberry,**" which is a species of *Potentilla* resembling the Strawberry in having short tufted stems, silky hairs, three toothed leaflets, and white flowers (Mar -May), but the receptacle knob does not swell or become juicy, nor does the stem send out runners so freely as in the Strawberry Besides the Barren Strawberry (*P fragariastrum*), there are several other common species of *Potentilla*, differing from it in having yellow flowers The **Tormentil** (*P tormentilla*), so common on heaths, is easily known by its erect or slightly creeping stems, stalkless upper leaves, small flowers (June-Sept) with (usually) four petals The **Creeping Cinquefoil** (*P reptans*) grows chiefly in hedges, has long creeping stems, leaves all stalked and with five toothed leaflets, and larger flowers (June-Aug) with (usually) five petals The **Silverweed** (*P anserina*) has long runners, numerous leaflets (large and small, often in regularly alternating pairs) covered below with silky down, and very large flowers (July-Sept), it grows commonly on roadsides and in waste places (often on sand and shingle beaches)

418. Hawthorn (*Crataegus oxyacantha*), although generally forming a much-branched hedge-shrub, may reach a height of thirty feet or even more, forming a tree (usually with a rounded head) with slender branches which often droop at the ends The bark on the old parts shows numerous longitudinal furrows dividing it into scales

The buds are small and have a few spirally arranged scales. They may grow out to form one or other of several types of branches. The bud may develop into (1) an ordinary shoot ("long shoot") on which the leaves are well spaced out and have large, green, toothed, persistent stipules, (2) a "dwarf shoot" on which the leaves are crowded and the stipules are small and soon drop, (3) a dwarf shoot ending in an inflorescence, (4) a "long thorn," towards whose tapering, pointed, hard end the leaves gradually become small, narrow, red scales, (5) a "short thorn," whose tip becomes pointed, hard, and red, and bears two small scales below and several still smaller ones higher up. Both long and short thorns may give off branches in later years. Examine as many plants as possible, noting how the general habit is influenced by the formation of these various types of branches.

The leaves (1 to 2 ins. long) are stalked, the glossy blade is narrow at the base and is divided into three or five lobes, which vary greatly in shape, but are usually more or less toothed. The stipules are roughly ½-arrow-shaped, toothed, sometimes persistent, and very variable in shape.

The flowers, arranged in clusters in such a way that they all reach nearly the same level when open, are built on the same general plan as those of the Dog Rose, but the stamens are fewer (about twenty) and there is only one carpel (sometimes two or even three). The sepals are short and narrow, they bend down when the flower opens. The five petals are rounded, white or pink, and attached to the rim of the receptacle-cup by a narrow base. The carpels resemble those of the Rose flower, but the stigmas are broad. The stigma is receptive before the anthers open, at this stage the outer stamens stand erect and the inner ones are bent inwards and downwards so that they do not touch the stigma and self-pollination is hindered.

Honey is produced at the base of the style and is partly concealed by hairs; the flowers are visited by various insects, but their peculiar smell appears to be specially attractive to flies. The odour is due to a substance (trimethylamine) which is also produced in decaying fish. The flowers can, in the absence of insect visitors, pollinate themselves, as a last resort arrangements for self-pollination are found in many plants. In fine weather *all* the stamens eventually move outwards and the anthers open, but on cold or wet days the inner stamens remain bent inwards and the outer ones shed their pollen over the stigma, causing self-pollination Why is Hawthorn popularly called "May"? Why is it often called "Whitethorn"? Do you know the "Blackthorn" (Sloe)?

The fleshy part of the fruit ("haw") is formed from the receptacle-cup, the top is thin, so that the hard akene or "nutlet" is here close to the surface The akene is sometimes called the "stone" because of its hardness, but it differs in nature from the true stone found in the plum or cherry The "haw" resembles a Rose "hip" in structure, differing chiefly in having a single akene (sometimes two) with a harder wall Cut the akene open to see the seed inside it The "haws" are eaten, and the single-seeded akenes dispersed, by birds When the seed germinates the cotyledons are carried up and become oval green leaves, the earliest foliage-leaves are very like the later ones

Compare the nature of a thorn, or spine, with that of a prickle Can a thorn be pushed off, like a prickle? Scrape the rind away from the base of a thorn and from the stem around it, also cut through the stem longitudinally, at the same time bisecting a thorn Do these experiments show that the thorn contains wood, which is continuous with the wood of the stem? Compare the thorns of Sloe (Blackthorn), Gorse, Buckthorn, and the prickles of Bramble, Raspberry, Borage, Teasel, with those of Hawthorn and Rose. How does a thorn (spine) differ from a prickle?

419. Rowan (*Pyrus aucuparia*) is, like Hawthorn, a small tree (ten to thirty feet high), but in high and exposed situations it may form merely a stunted shrub.

The Rowan is often called "Mountain Ash," but it is easily distinguished from the true Ash by its leaves, which are alternately arranged and have stipules, those of the Ash being in crossed pairs and without stipules The leaf has an end leaflet and from two to nine pairs of lateral ones Each leaflet is narrow, oblong, toothed, and from one to two inches long, smooth above, but downy below when young; the old leaflet has scattered hairs on the lower side, especially along the veins

The bark remains thin and smooth for several years and shows transverse lenticels, but later it becomes thick and furrowed The resting-buds are long, hairy, blackish, and pressed close to the stem They may, when they open, grow into ordinary long shoots, or into dwarf shoots which grow very slowly and bear each year only a few closely crowded leaves

The cream-white flowers are small but crowded in flat-topped inflorescences at the ends of short branches, the inflorescence is circular in outline (10 to 15 cms. diameter) The flowers (about 8 mm diameter) open in May or June, and closely resemble those of Hawthorn in structure, their peculiar odour being also due to the presence of trimethylamine and the stigmas maturing in advance of the anthers They are visited largely by flies and beetles, also by bees, the honey is protected by hairs on the lower parts of the short styles (generally three or four) Note that the axis of the inflorescence branches repeatedly (three or four times), but all the flowers are raised to the same level (of what advantage is this ?)

The fruits are globular (about 6 mm diameter), with scarlet skin and yellow pulp, the hard central part has (usually) three chambers or "stones," each containing a seed The three ovaries are practically united and the receptacle grows closely around them, so that the fruit has the same structure as the "pome" of Apple or Pear The berries ripen in August and September, becoming brilliantly coloured and fleshy (until then they are small, green, and hard), they are eaten largely by Thrushes, Redwings, Fieldfares, etc

420. The pome-bearing Rosaceae belong to *Pyrus* and allied genera. In addition to Rowan, there are 4 British species of *Pyrus*—Pear, Apple, Wild Service, White Beam **Apple** and **Pear** have simple ovate leaves, 20 sta, 5 cpls, with leathery pericarp, flrs in simple cymes or umbels, protogynous The Pear is a taller and more handsome tree than the Apple, its leaves are not downy below, even when young, buds not hairy, petals white, not tinged with red, anthers red, not white or yellow, styles free, not joined at bases; fruit never concave at base, even when rounded instead of pear-shaped, cells of fruit (in cross-section) have their outer margin rounded, not pointed, flesh gen with gritty particles, not found in Apple

In both Apple and Pear the flowering dwarf shoots ("spurs") arise from the larger buds, the smaller buds may grow into long shoots or non-flowering dwarf-shoots; the end of a shoot may turn hard and form a spine, but this does not occur so often as in Hawthorn and Sloe sharp-toothed, flrs (Mar, April), usually before the leaves, 10-20 mm. across, often solitary, K-tube bell-shaped with 5 blunt lobes, C 5, A 15 to 20, drupe blue-black, with dull "bloom," bitter, stone rough

Examine, if possible, the other 3 native British species of *Prunus*—Bullace, Gean, Bird Cherry—and the 2 species which often occur as escapes from cultivation—"Wild" Plum and Sour Cherry **Bullace** and **Plum** are closely allied to the Sloe, but have brown bark, pointed buds, drooping (never erect) fruits, and larger leaves, flrs (in pairs), and drupes (sweet) Bullace has few spines, leaves downy below, drupe about 1 in across, Plum has still larger parts, leaves downy on the ribs below, no spines, young shoots not hairy as in Sloe and Bullace, flrs after leaves (Apr, May), fruit often oval and violet or red instead of globular and blue-black

The **Gean** or **Wild Cherry** (*P avium*, the origin of the "Heart" and "Bigaroon" Cherries) has no suckers, is sometimes 60 ft high, with steeply-rising branches, bark has conspicuous transverse lenticels, and peels off in thin transverse strips, but is rough and longitudinally furrowed at base of tree, leaves droop on long stalks with 2 red glands below the pale green blade (oval, with pointed tip and double-toothed edge); buds pointed (leaf-buds) or blunt and rounded (inflorescence-buds), opening vegetative bud shows transitions between bud-scales and young foliage-leaves, and the latter secrete gum from glands on their teeth, flrs (May) in umbels of 2 to 6, K constricted at top, lobes entire, petals broad, limp, forming a spreading corolla; drupe sweet, without bloom, with staining juice The tree is often attacked by a fungus which causes "witches' brooms" (nest-like tufts of short branches, as in Birch) and prevents flowering, besides deforming the stems and leaves (on which the fungus spores are formed as a white coating, to spread the disease)

Sour or **Dwarf Cherry** (*P cerasus*, the origin of Morello, Duke, Kentish, etc, Cherries) differs from the Gean in several points — smaller, with reddish bark; more spreading, slender, and often drooping branches, numerous root-suckers thrown up, leaves dark bluish-green, more leathery, with short stalks, spreading instead of drooping, not hairy, infl -buds have *leafy* inner scales, flrs come before leaves and are smaller, K-tube not constricted, lobes bluntly toothed (*crenate*), petals firmer and more erect, drupe gen. red, acid, juice not staining, skin separates easily from flesh and flesh from stone; never found truly wild in Europe (original home not definitely known).

Bird Cherry (*P padus*) is a small tree (10 to 20 ft) with copious root-"suckers", smooth bark with short transverse lenticels; buds long and pointed, often curved; leaves short stalked, blade bulged at base, flrs (May) small (12-20 mm across) in long (3 to 5 ins) hanging racemes (sometimes erect), with short stalks, petals toothed, fl. protogynous (those of most Cherries are homogamous), drupe small (8 mm), black, bitter, more or less poisonous to man, but eaten by birds.

Examine the **Common** or **Cherry Laurel** (*Prunus laurocerasus*) and **Portugal Laurel** (*P lusitanica*), which are closely allied evergreen plants, often cultd., with long erect racemes of white flrs arising in axils of leaves of preceding year, and dark purple drupes. Cherry Laurel has large thick glossy leaves, with edge even or minutely toothed here and there, and 2 to 4 glandular pits on underside near base of blade; flrs (April, May) smell rather disagreeably; leaves taste of bitter almonds and are poisonous, but used in small quantities for flavouring. Portugal Laurel has smaller and more leathery leaves, darker in colour, regularly toothed, without glands; raceme shorter than leaves, flrs (June) smaller.

The **Peach**, and its variety the **Nectarine**, have rose-coloured cherry-like flrs (March, April), 1 or 2 together, before the leaves; drupe with velvety skin, fleshy pulp, wrinkled stone (smooth in Nectarine). **Almond** (probably the origin of Peach) has solitary flrs (Mar., Apr.) before leaves; drupe (ripe in Oct.) with velvety skin, firm (not fleshy pulp), splits to let out the pitted or smooth stone; seed (the part eaten) sweet or bitter in different varieties or sometimes on same plant. **Apricot** differs from Peach and Almond in having shining heart-shaped leaves, and in flowering earlier (Feb., Mar.), stone with one end pointed, the other blunt, and a groove on both sides.

423. *Spiraea* includes numerous species of shrubs, often cultd.; nearly all have the young twigs cinnamon-brown in colour and therefore conspicuous in winter, and freely produce suckers. The leaves vary greatly in different species, simple, entire, toothed, lobed, or pinnate-compound; flrs white or reddish, gen. small and in dense infls.; K 5-lobed, persistent; C 5; A 10 to 50, filaments gen. with broad bases; G 5, or more, rarely fewer or 1, gen. quite separate but sometimes joined at base; fruits = follicles. The **Willow Spiraea** (*S. salicifolia*), sometimes found in hedges and plantations but not native in Brit., is one of the commonest species, 4 to 6 ft. high, with simple serrate leaves (2 to 3 ins. long) and long cylindrical infls. of pink flrs (July, Aug.) with 5 cpls.

No true Spiraeas are native in Brit., though Meadowsweet and Dropwort are often (wrongly) given in "Floras" and other books as being species of *Spiraea*. These two plants belong to the genus *Ulmaria*, which consists of herbs, with one-seeded fruits (akenes). **Meadowsweet** (*U. palustris*), in damp places, has large compound leaves with a large 3-lobed end leaflet and alternate pairs of large and small side-leaflets, all white and downy on underside, small (6-8 mm.) flrs (June-Aug.) in a dense flat-topped infl. (5-15 cms. across), white; cpls. 5 to 9, twisted and horizontal. **Dropwort** (*U. filipendula*), in dry places, has nearly all its leaves basal ("radical"), not downy below, smaller (4 to 9 ins.); flrs in a loose infl., tinged with red; cpls. 6 to 12, straight and erect.

424. *Rubus* is chiefly repd. in Brit. by the innumerable kinds of **Bramble** or **Blackberry** (*R. fruticosus*, Fig. 126). The **Dewberry** (*R. caesius*) is distd. by having small prickles, few flrs. in infl., drupes few and large and covered with waxy bloom. The **Raspberry** spreads and multiplies largely by suckers—shoots which grow horizontally below the soil and then turn up and give rise to aerial shoots, the latter are usually biennial, flowering (June-Aug.) in their second year and then dying down, prickles on stem straight and slender, on flowering-branch curved; flrs drooping, greenish-white.

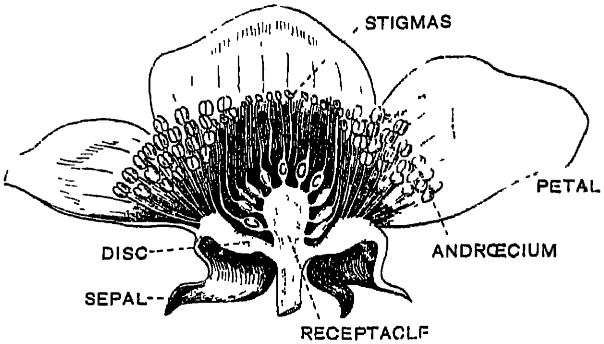


Fig 120 —Longitudinal Section of Flower of Blackberry.

425 *Geum* (Avens) has 2 Brit species, both erect perennials with numerous pinnate "radical" leaves (each with numerous paired side leaflets and a much larger end-leaflet), honeyed protogynous flrs, and akenes with persistent hooked style **Wood Avens** or Herb Bennet (*G. urbanum*) has erect yellow flrs (June-Aug) with K-lobes reflexed in fruit, it grows commonly in hedgerows. **Water Avens** (*G. rivale*) has drooping flrs (May-July), larger (2-4 cms across), with conspicuous red-brown K-lobes and orange petals, akenes in a head on a prolongation of the receptacle, it grows chiefly beside streams Several species of *Geum* are cultd.

426. *Dryas* is a small tufted shrubby creeping plant found in hill districts on limestone, often on the faces of cliffs, leaves small, white below, flrs (June, July) 2-4 cms, white; K-lobes 8 or 9; petals 8 or 9, oblong, A ∞, G ∞, akenes with long (2-5 cms.) feathery style

427 *Agrimonia* has 1 Brit species, **Common Agrimony**, in hedges, etc, with short woody rhyzome, pinnate leaves (3 to 7 ins. long, with 3 to 10 pairs of serrate leaflets), and long raceme of small (8 mm) yellow flrs (June-Aug.); K-tube (receptacle) top-shaped, covered with hooked spines, with narrow mouth; sepals 5, triangular, pointing inwards, C 5, A 5 to 10, sometimes more; cpls. 2, enclosed in K-tube, each with style and 2-lobed stigma projecting, K-tube becomes woody in fruit, raceme lengthens, and flower-stalks curve downwards

428. Lady's Mantle (*Alchemilla vulgaris*) has a short thick rhizome; aerial stem 6 to 18 ins. high, leaves rounded, 6- to 9-lobed, "radical" ones large and long-stalked (in rain the edges curl inwards, so that water is collected), flrs. (June-Aug.) in more or less flat-topped infls. (cymes), small (3 mm. across), yellowish-green, K-lobes 4, with 4 bracts (epicalyx), no petals, 4 sta., on mouth of K-tube, which is nearly closed by a honey-disc but allows the styles of the cpls. (2, often only 1) to project. **Parsley Piert** (*A. arvensis*) is a much smaller plant, annual, branched from base, leaves fan-shaped and 3-lobed, stalk short, flrs. very small, almost hidden by the stipules, bracts gen. absent, sta. 1 or 2; cpls. 1 to 3. The large species grow in moist pastures, the small ones in waste places on dry soil. A third species (*A. alpina*), perennial, with silky hairs all over except on upper side of leaf, grows on high hills.

429. The **Burnets** (*Poterium*) are erect perennials, with short rhizome, rosette of pinnate leaves with paired stalked leaflets, and small flrs. (June-Aug.) in dense long-stalked heads; K-lobes 4, stalked, cpls. 1 to 3, each with a much-branched stigma on a long style. Wind-pollination occurs in **Salad Burnet** (*P. sanguisorba*), common on chalk-downs, with small flrs. in mop-like clusters (8-20 mm. diam.), containing ♀ flrs. above and ♂ flrs. below, ♀ flrs. open first and have gen. 1 cpl., ♂ flrs. have 20 to 30 sta. with long hanging filaments. **Great Burnet** (*P. officinale*), in moist pastures, has herm. flrs. in an oblong head (1 to 1½ ins. long), which have a honey-disc round mouth of K-tube, only 4 sta. with short rigid filaments, and less branched stigmas; it is not so specialised as Salad Burnet for wind-pollination and retains more traces of descent from insect-pollinated ancestors.

430. [The **Medlar** (*Mespilus*) is a small tree, with spines in "wild" state, leaves oblong, entire or minutely serrate, woolly below, flrs. (May, June) solitary, large (1½ ins. across), white, on short stalk, K woolly, fruit brown, globular (½ to 1 in. diam.), with a large depression at top and large persistent K-lobes, stones (gen. 5) 1-seeded, large.]

431. *Cotoneaster*, gen. grown as trailing shrubs (some kinds evergreen), has gen. ovate leaves, flrs. (April, May) in corymbs, small, gen. pink, K-tube top-shaped; petals persistent, cpls. with free styles; fruit small, red, with 2 or 3 1-seeded stones.

432. [The **Common Quince** (*Cydonia vulgaris*) is a small straggling tree; flrs. (May) on "spurs," gen. solitary, large, A 20, cpls. 5, joined below to form 5-loc. ovary, each loc. with few ovules, styles free, with small stigmas, not as high as sta., pomes hard and bitter; seeds with gummy coats. **Japanese Quince** differs in producing its flrs. (Feb.-May) largely before the foliage-buds open, flrs. in a raceme, scarlet; A about 50, in 5 circles on funnel-like rec., loc. of ovary with many ovules; stigmas larger and lobed, higher than sta.]

433. Flower Mechanisms in Rosaceae.—In most Rosaceae the flowers, which are regular and show all degrees of perigyny, are insect-pollinated (except *Poterium*) and mostly visited by all sorts of insects In most cases honey is produced by the whole inner surface of the receptacle, or there is a ring-like nectary (disc, Fig 126) round the receptacle mouth within the insertion of the stamens, Dog Rose, Agrimony, Meadowsweet, and Dropwort are honeyless pollen-flowers Lady's Mantle and the smaller Potentillas are visited by flies, Cotoneaster chiefly by wasps

In *Prunus* and the larger-flowered Pyrus-types the stamens form a sort of palisade, which keeps out short-tongued insects, this is especially marked in flowers like those of Quince, which are largely visited by bees (the shorter-tongued ones only getting pollen) and whose receptacle is often bored by the bees The flowers are often more or less protogynous (Hawthorn, Sloe, Avens, Bird Cherry, Japanese Quince, etc), though (often in allied forms) sometimes homogamous (Common Cherry, Gean, Dropwort, etc) or protandrous (Roses, Potentillas, Meadowsweet, etc.) Self-pollination is apparently possible in all cases

QUESTIONS ON CHAPTER XVII

1 Why are the prickles on erect-growing Roses straight, while those on scrambling Roses are hooked?

2 Describe carefully the structure of a Rose flower Why is the Dog Rose called a "pollen-flower"?

3 Explain clearly the differences between the prickles of Roses or Brambles and the spines of Hawthorn or Sloe

4. Describe and compare, giving sketches, the fruits of Rose and Strawberry

5 Describe the different kinds of leaves on a Strawberry plant In what respects does a cultivated Strawberry differ from the Wild Strawberry?

6 How does the Wild Strawberry differ from the Barren Strawberry?

7 Describe the different forms of branches found on a Hawthorn.

8 Describe the flower of Hawthorn By what insects is the flower visited, how does it attract insect-visitors, and how is self-pollination hindered?

9 Describe the fruit of Hawthorn, and compare it with the fruits of Rose, Strawberry, and Rowan To which of these plants is the Hawthorn most closely allied?

10 How could you distinguish in winter, in the absence of leaves, flowers, and fruits, between Rowan ("Mountain Ash") and the real Ash-tree?

11 Compare, by means of a series of sketches with the parts labelled, the fruits of Cherry, Bramble, Strawberry, Potentilla, Avens, Agrimony, Rose, Hawthorn, Rowan, and Apple. Deal only with fruits you have actually examined.

12 Why are Cherry, Sloe (Blackthorn), Plum, Almond, Cherry Laurel, and Portugal Laurel all placed together in the same genus (*Prunus*)? In what respects do they agree? Mention some of their differences

13 Why are Rowan, Apple, Pear, Service-tree, and White Beam all placed in the same genus (*Pyrus*)? In what respects do they agree? Mention the distinguishing characters of each plant, dealing only with those you have examined

14 Mention the commonest species of Potentilla, noting the distinctive characters of each, the months when each is most abundant in flower, and the habitat in which each occurs

15 Mention ten Rosaceous plants, of which eight must be British. Draw careful longitudinal sections of the flowers of four of them

16 Give diagrams with brief descriptions, showing the variation in the form of the ovary and receptacle in the *Rosaceae* Give examples of each case Name the chief British genera of this order.

CHAPTER XVIII.

THE WALLFLOWER FAMILY.

434. Wallflower (*Cheiranthus cheiri*) can be obtained in flower at almost any time of year. Charlock, Turnip, and other plants of this easily recognised family should also be examined.

Note the perennial erect stem, woody and cork-clad below, green and five-angled above, the crowded sessile lance-shaped leaves, entire or slightly toothed, arranged in five rows; the numerous branches, often ending in a bractless raceme of flowers (rich red or purplish brown in garden plants, yellow in the wild form which grows chiefly on old walls). The younger parts, including the sepals (outer side) and the ovary of the flower, bear curious hairs, not easily seen but plainly felt on drawing a leaf (underside) across one's lips. These hairs are pointed at each end and lie parallel with the surface of the stem or leaf, attached by a short stalk at the middle, like a compass-needle, they are well adapted for preventing slugs and snails from crawling over the plant. Tear off a strip of skin (epidermis) from stem or leaf, mount in water, and draw some of the hairs seen with the microscope.

In a raceme note that all the flowers are at first kept nearly at the same level, owing to the longer stalks of the lower flowers, but as the lowest flowers wither (after pollination) the raceme-axis grows on and the next flowers to open take their places, until all the flowers have opened and been pollinated, then the axis keeps on lengthening and spaces out the fruits. It is easy to note the exact position of each part of a flower with reference to the stem or raceme-axis (Figs. 127, 128).

Note the four free erect purplish sepals, in two pairs, one pair (right and left) a little below (outside) the other (front and back) pair, the two lower (outer) sepals are bulged at the base Note the four free petals, each with a narrow erect lower part (claw) and a broad spreading upper part (limb),

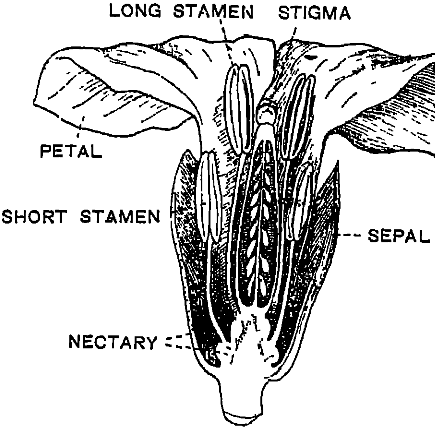


Fig 127 —Vertical Section of Wallflower

the two outer short stamens (one opposite each of the bulged sepals) and the four inner long ones (in two pairs, a pair opposite each inner sepal), the cylindrical ovary with two rounded stigma-lobes on a very short style, the green squarish nectaries at the bases of the outer stamens

The honey can only be reached by fairly long-tongued bees and butterflies, they stand on the platform made by the spreading petal-limbs In probing for the honey, which collects in the pocket-like bases of the outer sepals (each of the two outer stamens stands out, leaving a space between it and the pistil), a bee will rub against an anther with one side of its head and against the stigma with the other side. The fragrant flowers are much visited by bees and butterflies, but are self-pollinated in the absence of insect-visits

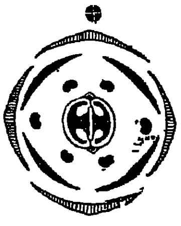


Fig 128.—Floral Diagram of a Crucifer.

The structure of the ovary is best seen by examining the fruit or "pod" into which it grows; it can, however, be made out with a lens The ovules are attached to the inner wall of the ovary at opposite sides (front and back), but from each placenta a plate of tissue grows (when the flower is developing) to meet a corresponding plate from the opposite placenta, so that the ovary becomes two-chambered, though the ovules are on *parietal* placentas

When the "pod" ripens, the wall splits off into two valves (right and left) from below upwards, leaving a frame consisting of the thickened placentas (each bearing two rows of seeds) with the thin partition ("false septum") stretched between them (Fig 110), the "pod" opens in dry weather and the thin flat seeds may be carried by the wind This kind of "pod" is termed a *siliqua*, it is very characteristic of the Wallflower Family, though occurring in a few other families besides.

435. The Wallflower Family (Cruciferae) is easily recognised by the cross-like arrangement of the four petals, the general similarity of the other flower-parts to those of Wallflower, and by the fruit, which is nearly always a siliqua or a silicula (short broad siliqua)

Since the family is remarkably uniform in flower-structure, it is not easy to divide it into groups or even to define the genera The groups of genera dealt with in the following notes are distinguished by their fruits (1) Fruit longer than broad (siliqua) —Wallflower, Stock, Honesty, *Nasturtium, Hesperis, Arabis, Cardamine, Sisymbrium, Brassica.* (2) Fruit short (silicula), flattened at right angles to partition —*Capsella, Lepidium, Iberis, Thlaspi* (3) Fruit short, but not flattened at right angles to partition —*Draba, Erophila Alyssum, Cochlearia* (4) Fruit divided into several one-seeded joints (lomentum) —Radish. (5) Fruit of two superposed joints —*Crambe, Cakile*

436. The **Stocks** cultd. for their flowers in gardens are species and varieties of *Matthiola* and *Malcolmia* (Virginian Stock), the former genus being represented by 2 wild species (rare) on the coast in south England

Many other Crucifers grow on or near the coast (*Cakile, Crambe,* Wild Cabbage, Wild Radish, *Cochlearia,* Sweet Alyssum), but have given rise under cultn (for flowers or as food) to numerous varieties grown inland The Stocks have large flrs like those of Wallflower, with long-clawed petals, [*Matthiola tristis* (cult) is scented in the evening and visited largely by moths, as are the large purple flrs. of *Hesperis* (Dame's Violet, cultd) The large oval pods of Honesty (*Lunaria*, cultd) are used as ornaments after removing the valves to display the shiny partition, the seeds are flat and winged].

437. *Nasturtium* includes the Watercresses [the "Nasturtium" or "Indian Cress" of gardens is a totally different genus (*Tropaeolum*) of another order], the **Common Watercress** has hollow stems, sometimes floating, pinnate leaves with a large end-leaflet and 3 to 6 pairs of smaller side-leaflets, short racemes of small white flrs (May-Oct) and short (6 mm) pods There are 3 other Brit species, not so common, with yellow flrs, in moist places *N sylvestre* (creeping rhizome, leaf with numerous narrow leaflets, pods 12 to 20 mm long), *N palustre* (stem erect, leaf with few leaflets and the end one very large, flrs. very small with petals shorter than sepals), *N amphibium* (stem 3 or 4 ft. high, submerged leaves pinnately cut, upper ones entire and toothed, petals longer than sepals).

438. *Cardamine*, distd. by having pinnate leaves, has 2 common Brit species *C. pratensis* (**Cuckoo-flower** or **Lady's-smock**), leaves all pinnate, large lilac or nearly white flrs (April-June), growing 1 to 2 ft high in wet places; *C hirsuta* (**Hairy Bittercress**), on banks, walls, etc, leaves mostly in a rosette, with rounded leaflets, flrs (Mar -July) small and white, sta gen 4, valves of ripe fruit are elastic and suddenly curl out and jerk the seeds away

439. *Arabis* (**Rockcress**) has several Brit species, none very common, in dry places, with spoon-shaped toothed "radical" leaves and narrow sessile upper (stem-) leaves, flrs gen white, several kinds are cultd. as rockery and border plants

440. *Sisymbrium* has 3 common Brit. species *S alliaria* (**Garlic Mustard, Jack-by-the-hedge,** with strong garlic smell) has during winter a rosette of long-stalked kidney-shaped "radical" leaves and in spring sends up flowering stems 1 to 3 ft high, flrs (April-June) white, pods 2 or 3 ins long, *S officinale* (**Hedge Mustard**), very common in dry waste places, has a most characteristic habit owing to its hard stems branching at right angles, hairy leaves with a few narrow lobes, very small yellow flrs. (June-Aug.), and narrow tapering pods pressed closely to the stem, *S thaliana* (**Thalecress**), annual, leaves mostly "radical," oblong and stalked (very few on stem, narrow, sessile), flrs white, pods long and more or less 4-angled

441. There are about 7 Brit species of *Brassica*, all with rather large yellow flrs., beaked pods, and gummy-coated seeds; they fall into 2 sections: (1) Cabbage and Turnip, with sepals erect, (2) Mustard and Charlock, with sepals spreading.

The **Wild Cabbage** (*B. oleracea*), on sea-cliffs in S.W. of England and Wales, has a stout erect woody rhizome bearing smooth obovate leaves, covered with bloom, and long racemes of pale yellow flrs. From it have arisen by cultn. the numerous and interesting cabbage races. In the least improved races (borecole, cow-cabbage, Scotch kail) the large fleshy leaves are still open and loose; in the other races they form a compact "heart" (ordinary green and red cabbages with smooth leaves, savoy and curled kale with wrinkled leaves), or the stem grows up and bears fleshy cabbage-like buds (brussels sprouts), or fleshy infls. (cauliflower, broccoli); the stem itself becomes thick and fleshy in kohl-rabi or "turnip cabbage."

Wild Turnip (*B. campestris*), a common weed in cult. soil, has its lower leaves pinnate and its upper oblong and stem-clasping, but they vary greatly in shape; the racemes approach the corymb form, and the flrs. are bright yellow. From it are derived the cult. turnips and swedes with swollen roots, also the rapes (root not swollen) whose seed yield rape and colza oil (rape has black seeds, colza brown seeds).

Charlock (*B. sinapis*), very common in cornfields, etc., is annual, hairy, with lobed leaves and large (20 mm.) flrs., pods 1½ to 2 ins., standing out from stem. **White Mustard** (*B. alba*), whose seedlings are used in salads, is like Charlock, but its flrs. are smaller and its pods have few seeds. **Black Mustard** (*B. nigra*), wild on sea-cliffs, is also annual, but its leaves are not hairy or lobed, and its 4-angled short (6-12 mm.) pods are pressed against the stem.

442. The commonest Crucifer with short pod (silicula) is **Shepherd's Purse** (*Capsella*), with triangular or heart-shaped pods, a polycarpic annual (*i.e.* germinating, flowering, and fruiting several times in succession each year) found in flr. nearly all the year; lower leaves stalked, pinnately-lobed (or entire), gen. forming a rosette; upper leaves sessile, spearhead-shaped; infl. more or less flat-topped at first; flrs. small, white.

443. *Lepidium* includes **Common Cress** (seedlings used for salads) and a few Brit. species; the flrs. are minute and white, often without petals, sta. often reduced to 4 or 2, pod very small and scale-like with 1 seed in each chamber; *L. ruderale*, in waste places chiefly near the sea, annual, radical leaves much divided into narrow lobes, upper ones narrow and entire, flrs. with minute petals or none, 2 sta.; *L. campestre* (**Pepperwort**), fairly common in fields and roadsides, has comparatively large pods (6 mm.).

444. Candytuft (*Iberis*) has 1 Brit. species (*I. amara*), annual, in cornfields, but varieties are cultd. for their showy flrs., which are in flat infls. (corymbs); all the flrs., but especially the *outer* ones, in a corymb (Fig. 93) have the 2 lower (outer) petals larger than the other 2 (this makes the corymb more conspicuous to insects); note the ribbed stem with short hairs on the ribs, the pod with 1 seed in each chamber, the long style.

445 *Thlaspi* (**Pennycress**) has 1 common Brit. species (*T. arvense*), in dry fields, annual, with stalked entire radical leaves, which soon wither, and arrow-shaped stem-leaves, stem 1 to 2 ft., slender, gen. unbranched, flrs. (May-July), white, ¼ in. across, pod with a broad wing, deeply notched at top with the short style in the notch.

446. *Draba* (*Erophila*) *verna*, **Vernal Whitlow-grass,** common on walls and dry stony soil, is an annual with all its leaves in a rosette, leaves ½-1 in. long, entire; raceme 1-1½ ins. long, with rather few small (3-6 mm. diam.) white flrs. (Mar.-June), petals 2-lobed; pods 6-8 mm. long, containing about 30 minute seeds. Can you see the advantage to a spring flowering annual plant of having *numerous* seeds? There are 4 other Brit. species of *Draba*, chiefly on hills, they have leaves on the flowering-stems as well as the rosette-leaves, many species are cult. in rockeries and are mostly perennials, with *few-seeded* pods and gen. hairy leaves.

447 *Alyssum*, often cultd., has small entire leaves [often hoary with closely-pressed hairs (gen. star-shaped)] and dense infls. of small white or yellow flrs., pods short, few-seeded, *A. maritimum*, in waste places near the sea (a doubtful native), is cult. as "Sweet Alyssum," its white flrs. being scented. [The closely allied genus *Aubrietia* is also much cultd.]

448. *Cochlearia* has 1 common Brit. species, *C. officinalis* (**Scurvy-grass**), found on sea-shores and on high hills, perennial, with cordate fleshy radical leaves, flrs. white (May-Aug.), 6-8 mm., pod nearly globular (3-6 mm. diam.), *C. armoracia* (**Horse Radish**), cultd. (part eaten = fleshy rhizome), but often found apparently wild, with long-stalked (1 ft.) oblong radical leaves and sessile narrow stem-leaves, flrs. (May, June) in panicled racemes, small (8 mm. across) and white, fruit not ripened in Brit.

449 *Raphanus* (Radish), *Crambe* (Sea Kale), and *Cakile* (Sea Rocket) are each repd. by a Brit. species (*maritima*) found at the coast. Sea Radish (biennial, roughly hairy, leaves many-lobed and toothed, flrs. yellow in long racemes) is probably the parent of the **Wild Radish** (*R. raphanistrum*, "White Charlock"), which is annual in cornfields, less hairy, with large (2 cms.) white flrs. (May-Sept.), pod 1 to 3 ins. with a beak about 2 ins. long, also the cultd. Radish, which has a long swollen root. **Sea Rocket,** common on sandy and shingly beaches, annual, with zigzag branches, broad fleshy leaves (2 or 3 ins. long), flrs. (June, July) white or purplish, 1 cm. across, in corymbs; pod with two joints, each with 1 seed. **Sea Kale,** with same habitat but not common, has a fleshy creeping rhizome, large (6 to 10 ins. long) broad stalked fleshy bloom-covered cordate radical leaves (stem-leaves few and small), flrs. (June-Aug.) 1 cm. across, white, in much-branched corymbs, pod with a slender seedless lower joint and a globular 1-seeded upper joint.

450. Flower Mechanisms in Cruciferae.—The flowers are generally homogamous, though often protandrous but with a relatively long overlapping period during which self-pollination may occur. The flowers are visited by flies when the sepals are short or spreading and the petals short-clawed, and some of the small-flowered types (*e g* Shepherd's Purse, whose flowers often have only 2-4 stamens when produced in the colder months) are regularly self-pollinated The larger flowers, in which the sepals are erect and hold the clawed petals together so as to form a sort of flower-tube, are visited by bees and butterflies, the honey being partially concealed and protected from rain The large light-coloured evening-scented flowers of *Hesperis* and some Stocks, etc , are visited by moths

Note the general tendency of the raceme to form a round- or flat-topped inflorescence while the flowers are opening—the raceme is nearly always *corymbose*—so as to make a conspicuous mass of flowers. This is especially marked in Candytuft, where the flowers, especially the outer ones, have a zygomorphic corolla After flowering, the raceme-axis lengthens out, carrying up the fruits for more effective seed-dispersal

QUESTIONS ON CHAPTER XVIII

1 Describe fully the carpels of the Pea and of the Wallflower, and state the uses of the various parts

2 Describe the flower structure and pollination of Wallflower, with sketches.

3. Describe the parts of the plant which are eaten in the following: Turnip, Cabbage, Brussels Sprouts, Cauliflower, Sea Kale, Radish, Mustard, Watercress, Common Cress, Horse Radish, Kohl-rabi.

4 Describe the Cruciferae which grow at the sea-coast How do they differ from most plants which grow inland?

5. If you had to teach a Botany class in a large town, how would you most easily obtain material with which to work? Mention some of the objects you could readily get, and the points of interest you could show on them

6 Describe the Crucifers which grow in or near streams.

7. Write an account of the fruits of Cruciferae, noting any peculiar forms or methods of seed-dispersal, with sketches

8 Note any points of interest connected with the following plants. Shepherd's Purse, Candytuft, Hairy Bittercress, Sea Rocket, Honesty, Dame's Violet, Garlic Mustard, Vernal Whitlow-grass

9 Write an account of the methods of pollination met with in Cruciferae

CHAPTER XIX.

THE CAMPION FAMILY

451. Greater Stitchwort (*Stellaria holostea*).—This well-known plant, whose white star-like flowers are produced so abundantly in hedgerows in spring and early summer (April-June), is a herbaceous perennial, the shoots dying back in winter The branches produced in spring arise from buds in the axils of last year's leaves on the old parts of the stem

The weak slender stems are four-angled, and easily broken across at the swollen "nodes," which bear the leaves in crossed pairs. The stems are not strong enough to grow erect, except when the plants are crowded and support each other, but they often climb or scramble over the hedge-forming shrubs The narrow leaves (1 to 4 ins long) are at first erect (parallel with the stem), but as the stem with its long internodes (due partly at least to the plant being *shaded*) insinuates itself among the branches of the hawthorns, etc , the leaves spread out and thus hook on to the supports, the four rough ridges of the stem also helping in this method of climbing

The grass-like form of the leaves is also well adapted to enable the Stitchwort to grow among long grasses and to get its share of air and light in the struggle which is so keen in crowded hedgerows The leaves are rigid and sessile, their long narrow shape making a stalk unnecessary, and the bases of each pair are joined around the stem, forming a sort of cup in which water can be caught and absorbed by the stem "nodes" Note the hairs covering the younger parts of the stem and the edges of the leaves, and the single well-marked vein (midrib), with indistinct side-veins, of the leaf.

Most of the shoots end in an inflorescence, which is a good example of the *dichasium* or biparous cyme, characteristic of this family though found in several others. The stem ends in a flower which grows out on a long thin stalk, then a branch arises in the axil of each of the two leaves, this branch bearing a pair of leaves and ending in a flower, and so on. This branching may occur quite regularly as often as six times, but as a rule the full number of flowers is not formed every time of branching.

The flower (1 to 2 cms. diam.) has five free sepals, five petals twice as long as the sepals and each deeply notched, ten stamens in two circles, and a rounded ovary with three styles The numerous ovules are on a free central axis The cup-like flower contains honey, secreted by glands at the bases of the stamens on the receptacle and available to short-tongued insects

The flower is protandrous, the two circles of stamens successively rising and shedding their pollen before the styles diverge The inner surface of each style is covered with stigmatic hairs, so that pollination does not occur until the styles spread out and expose their stigma-surfaces. The flowers are usually cross-pollinated by the various insect-visitors, but self-pollination may occur as a last resort by the spreading styles touching the anthers.

The fruit is a thin-walled globular capsule, which splits at the top into six teeth, the seeds being shaken out when the wind rocks the plant about (censer mechanism).

452. Common Chickweed (*Stellaria media*) is one of the commonest and most variable plants, but is easily recognised by the line of hair on the cylindrical stem, changing in position at each "node." Water poured on the leaves runs down these lines, which evidently serve to dry the plant after rain and to convey water to the root, some of it probably being absorbed at the "nodes," where it collects in a drop between the bases of the opposite leaves The leaves are ovate and pointed, but variable in size, the lower ones are stalked, but the upper (those coming off above the first flower of the infl) are sessile The flowers are much smaller than in Stitchwort, the petals are generally shorter than sepals, stamens generally only three to five, rarely as many as ten. The plant is a polycarpic annual, flowering all the year round, in winter the flowers are often cleistogamic, sometimes without petals, and in any case are homogamous and self-pollinated in the absence of insect-visitors (flies chiefly).

453. The other Brit. species of *Stellaria* are perennials. **Lesser Stitchwort** (*S. graminea*), in dry fields and hedgerows, resembles Greater Stitchwort in most respects, but has narrower leaves, sepals joined at bases, and perigynous stamens; the capsule is egg-shaped; the flowers (May-Aug.) are rather smaller and not so markedly protandrous. **Bog Stitchwort** (*S. uliginosa*) also has the stem 4-angled and the sepals joined, but the cyme has very few flowers (May-July), and these are small (¼ in. diam.), with petals shorter than sepals. **Marsh Stitchwort** (*S. palustris*) also has 4-angled stem, united sepals, and egg-shaped capsules, but petals longer than sepals, while **Water Stitchwort** (*S. aquatica*) has broad leaves, flowers ½ in. across, and large (1 in. long) ovoid capsules surrounded by the free sepals, which enlarge after flowering, and differs from the other species in having 5 styles and 10 capsule-valves; these two species are not so common as the other three.

454. Red Campion (*Lychnis diurna*) is very common in hedgerows and damp, shaded places. It has a thin branching rhizome, giving off erect (1 to 3 ft. high) flowering shoots, with stalked obovate "radical" leaves (3 to 6 ins. long) and narrower sessile upper leaves, the whole shoot is covered with soft hairs and the cylindrical stem has swollen nodes.

The flowers (May-Sept.) are unisexual, and the male and female plants are easily distinguished, as a rule, even before flowering. The female plants are usually more robust, with thicker stems and larger leaves. The flowers (about 2 cms. across) have a hairy, reddish, gamosepalous calyx, with five pointed teeth, corresponding to five ridges on the long (½ in.) calyx-tube; in the female flower the calyx is more globular than in the male. The five petals are free; each has a narrow vertical stalk (claw) and a broad spreading, horizontal, deeply cleft blade, with a two-lobed scale at junction of stalk and blade. The five claws, held together by the tubular calyx, form a deep flower-tube, so that only long-tongued insects (bees, butterflies) can reach the honey, the five spreading blades serving as a platform, while the scales form a collar or "corona" and keep out small insects, besides helping to drotect the honey and pollen.

The male flower has ten stamens, five being longer than the alternate five (are the long ones opposite petals or calyx-teeth?). Sometimes the anthers contain, instead of pollen, a powdery brown or black mass—the spores of a smut-fungus, which are carried from flower to flower, like pollen, by visiting insects. There is often a rudiment of the pistil in the centre of the male flower. The female flower has an egg-shaped ovary with five long spreading styles, and sometimes contains rudimentary stamens.

The capsule, nearly globular, opens by ten teeth, which curve outwards, leaving a wide opening; the short flower-stalk remains erect, and the censer mechanism is more efficient than in the Stellarias.

455. The **White** or **Evening Campion** (*L. vespertina*) resembles Red Campion in structure, but grows in drier and more exposed places, often in fields as well as hedgerows; its flrs. (May-Oct.) are white and only open in the evening, when they are fragrant (those of Red Campion, which remain open all day, are scentless) and visited by moths.

Two other species of *Lychnis* are common; both differ from Red and White Campions in having protandrous flrs. with both stamens and pistil.

Ragged Robin (*L. flos-cuculi*), perennial, in moist fields and beside streams, has hairless shoots with lanceolate leaves; the blade of each petal is divided into four narrow lobes, giving the drooping rosy flrs. (May, June) a characteristic look; the capsule is egg-shaped and opens by 5 teeth only.

The **Corn Cockle** (*L. githago*), annual, is a beautiful and common cornfield weed; stem 1 to 2 ft. high, only slightly branched; the branches and the long (2 to 5 ins.) lanceolate leaves are nearly erect, making a small angle with the stem (why is this habit advantageous to a plant growing among tall corn?); stem, leaves, and calyx covered with long hairs; flrs. (June-Aug.) few, large (3-5 cms. across), pale purple, scentless; calyx-tube leathery, 3-4 cms. long, ribbed, teeth large and projecting beyond corolla; petals without scales and with blade only slightly notched or entire.

456. The Campion Family (Caryophyllaceae) is easily recognised by the opposite (decussate) simple, generally entire, leaves, stem usually with swollen nodes, regular flowers in dichasia (biparous cymes, in which one side generally outgrows the other and branches more freely), ovary generally with free central placenta bearing numerous ovules in double rows corresponding to the number of carpels (indicated by number of styles), sometimes showing at base traces of partitions

I. Sepals free (or slightly joined at bases), flower shallow, petals short (**Alsineae**)	
A Fruit an akene	*Scleranthus.*
B Fruit a capsule.	
1 Stipules present	
a. Styles 5, capsule 5-valved	*Spergula*
b Styles 3, capsule 3-valved	*Spergularia.*
2 No stipules	
a Petals entire	
i Leaves free, styles 3	*Arenaria.*
ii Leaves joined, styles 4 or 5	*Sagina.*
b Petals notched.	
i. Capsule round or egg-shaped	*Stellaria.*
ii Capsule cylindrical	*Cerastium.*
II. Sepals united, flower deep, petals clawed (**Sileneae**).	
A Styles 5	*Lychnis.*
B Styles 3	*Silene.*
C. Styles 2.	
1. Leaves very narrow ; bracts below calyx	*Dianthus.*
2 Leaves broad , no bracts	*Saponaria.*

457. *Scleranthus annuus* (**Knawel**), in fields and waste places, a frequent garden weed, is a small tufted plant with slender stems, opposite awl-shaped curved leaves (½-1 in long) with bases joined round stem at nodes , flrs (June-Sept) very small (6 mm. across), green, star-like, solitary or in small cymes; sepals joined, with 4 or 5 pointed lobes , no petals ; sta 5 to 1, rarely 10 ; styles, 2 with small knob-like stigmas , flrs visited by flies, but largely self-pollinated ; fruit a small 3-sided akene

458. *Spergula arvensis* (**Spurrey**), a hairy annual, in cornfields, etc. ; stems branched at base , leaves ½- 1½ ins long, with grooved underside and small scaly stipules ; flrs. (June-Aug.) small, white ; K 5, C 5, A 5 or 10, G (5) ; capsule globular, seeds numerous.

459. *Spergularia* has 2 common species *S rubra* (**Sand Spurrey**) in sandy and gravelly soil ; stem much branched at base, branches prostrate and spreading, 4 to 12 ins. long ; leaves ¼ to ½ in. flat ; flrs. (June-Sept) on short stalks, 6 mm. across, rosy, closing at about 4 p m ; petals gen shorter than sepals , K 5, C 5, A 5 or 10, G (3). **Sea Spurrey** (*S marina*), in salt marshes and on rocks near the sea, is perennial and has longer and more fleshy leaves, ½-cylindrical ; no hairs ; flrs. larger, long-stalked ; capsule larger (8 mm.), seeds winged.

460. *Arenaria* (**Sandwort**) has several species, mostly local (some only on high hills), 3 being common:

Three-nerved Sandwort (*A. trinervia*), in hedgebanks, is a hairy diffusely-branched annual, branches 4 to 18 ins. long, leaves stalked, ovate, pointed, ½ to 1 in. long, with 3 main veins, flrs. (May-July) white, 6 mm. across, long-stalked, protogynous, petals shorter than sepals, capsule globular, shorter than sepals, K 5, C 5, A 10, G (3).

Thyme-leaved Sandwort (*A. serpyllifolia*), annual, chiefly on wall-tops and in sandy fields, is similar in habit, but has shorter and more rigid leaves, almost sessile, and smaller flrs. (June-Aug.), ⅛ in. across.

Sea Purslane (*A. peploides*), very common on sandy coasts, is perennial with a creeping rhizome giving off erect branches 4 to 12 ins. long; leaves dark green, ¼ to ½ in., fleshy, ovate, acute, curved back, with leathery edges, in 4 regular rows, flrs. (May-Aug.) in groups of 1 to 3, 6 mm. across, polygamous, petals of ♂ flr. as long as sepals, of ♀ flr. shorter, nectar-ring 10-lobed; A 10, long and short alternating, capsule gen. 3-valved, fleshy, globular, with only 1 or 2 large seeds, this is one of the few plants that can survive being buried under shifting sand, its branches growing up to the surface again.

461. Pearlwort (*Sagina*) has 3 common species: *S. procumbens*, on paths, banks, wall-tops, etc., perennial, much branched, branches 1 to 9 ins., leaves ¼ to ½ in., narrow, blunt, flrs. solitary, parts gen. in 4's, petals very small, May-Sept., homogamous, self-pollinated. *S. apetala*, in similar places, but also with a seaside variety, is annual, with wiry ascending branches, small leaves (2-6 mm.), small green flrs. (2 mm. diam.) with no petals (or minute ones). *S. nodosa* (**Knotted Pearlwort**), in wet sandy places, heaths, bogs, perennial; branches 4 to 12 ins., curved, rooting at nodes, much the largest kind of Pearlwort; leaves awlshaped, ¼ to ½ in. long, flrs. (July, Aug.), single or in pairs, 6 mm. across, petals and capsules much longer than sepals; parts of flr. in 5's.

462. Mouse-ear Chickweed (*Cerastium triviale*), a variable plant, very common, gen. perennial and hairy, has flrs. like those of Chickweed, but the capsule (twice as long as sepals) is cylindrical and curved; the flr.-stalk, erect at first, bends down after flowering and rises again when the capsule is ripe. There are several varieties of *C. triviale*, with different numbers of sepals, petals, and stamens, and so on, but *C. arvense* is distd. by having petals twice as long as sepals (it is a hairy perennial with narrow leaves, found chiefly in dry hill pastures), while *C. quaternellum*, in sandy and gravelly places, is a small erect (2 to 6 ins.) wiry annual with narrow (½ to 1 in. long) leaves, quite hairless, white flrs. (May, June), on long stiff stalks, K 4, C 4, A 4, G (4), petals entire (shorter than sepals), capsule 8-toothed, and is often put in a separate genus (*Moenchia*) in Floras.

463 [*Gypsophila* ("Chalk-plant," "Gauze-Flower"), cultd. annuals with white or pink fls. which are gamosepalous, but have short petal-claws so that the flr. is shallow and visited by a greater variety of insects than the other Sileneae.]

464. *Silene* has several Brit. species, the commonest being **Bladder Campion** (*S. inflata*), perennial, 2 to 3 ft. high; leaves 1-3 ins. ovate or oblong, flrs. (June to Aug.) numerous, 20 mm. across, white, drooping, protandrous, with a cylindrical internode (disc, honeyed) between K and C, K inflated, ♂ and ♀ flrs. occur as well as herm., flrs. largely visited by butterflies and moths.

Sea Campion (*S. maritima*), on sea-shores (esp. shingle-beaches), also on high hills, is very similar, but has more fleshy leaves, fewer flrs. (1 to 4) in each infl., petals not so deeply notched and with larger scales (corona) at top of claw (2 scales to each petal).

The other Brit. species are not common, but many (including several tufted small-leaved Alpine kinds) are cultd. (various species of "Catch-fly"), some having sticky hairs, some of the Silenes are beautiful examples of moth-pollinated fls., and the ovary is often 3-celled below the middle, the partitions being incomplete.

465. *Dianthus* (Fig. 129) is repd. by a few Brit. species, none very common and some not really natives, but many (Pinks, Carnations, Sweet William, Picotees) are cultd.; they have narrow leaves, often with bluish bloom, very protandrous flrs. adapted to butterflies, with overlapping bracts at base of calyx, petal-blades often fringed, styles 2 (not diverging until the 10 sta. have emerged and dehisced, 5 at a time), capsule 4-toothed.

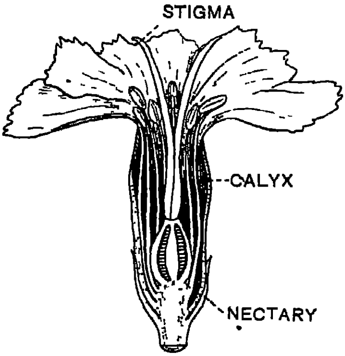


Fig. 129.—Longitudinal Section of Flower of Clove Pink.

466. *Saponaria* (**Soap-wort**, leaves forming a soapy lather with water) has broad spoon-shaped leaves, but (apart from absence of bracts below calyx) the flrs. are like those of *Dianthus*; several species are cultd., *S. officinalis* (perennial, with white fleshy creeping rhizome giving off runners) occurs apparently wild in Brit., chiefly by roadsides and often near the sea.

467. Flower Mechanisms in Caryophyllaceae.—There are two distinct types of flower structure in this family In the lower type **(Alsineae)** the flower is wide open, the sepals being free or (Knawel, Lesser and Bog Stitchworts) joined at the base only, and the petals sessile or having only short stalks (claws) The flowers of *Stellaria* are more or less perigynous The honey, secreted by a narrow ring, or by 5 or 10 glands, at the bases of the stamens, is accessible to short-tongued insects, though those with rather large flowers (*e g* Greater Stitchwort) are also visited by bees

Knawel, Procumbent Pearlwort, and Chickweed (*Stellaria media*) are homogamous and largely self-pollinated, Chickweed having in winter cleistogamic flowers. These, as well as the Sandworts and Spurreys, are visited by flies *Sagina nodosa*, *Cerastium*, Lesser Stitchwort, and the Spurreys (*Spergula* and *Spergularia*) are more or less protandrous but capable of final self-pollination, while Greater Stitchwort is almost completely protandrous with but little self-pollination. *Arenaria trinervia* is exceptional in being protogynous, while *A peploides* is polygamous

In the **Sileneae** the flower is made tubular (usually deep, but rather shallow in *Gypsophila*) by the gamosepalous calyx, the petal-claws and stamens partly filling the tube and making the honey (secreted on an "internode" of the receptacle between calyx and carolla) inaccessible to any but long-tongued insects (bees, butterflies, moths), small insects being further excluded by the "corona" of scales on the petals in *Silene* and *Lychnis* (exc *L githago*). The Sileneae are generally very protandrous, the Red and the White (Evening) Campions are dioicous, while Bladder Campion is polygamous

In most cases butterflies are probably the chief visitors, but Evening Campion and several kinds of Catchfly are moth-pollinated, the flowers opening and becoming heavily scented only at night and having conspicuous white or pale corollas In *Silene nutans* the flower opens during three successive nights, five stamens shedding their pollen on each of the first two nights and the styles protruding on the third. In the night-flowering Catchflies the petals remain curved inwards during the daytime.

QUESTIONS ON CHAPTER XIX.

1. Describe the typical inflorescence of caryophyllaceae. In what other families does a similar inflorescence occur, and how would you distinguish their flowers from those of Caryophyllaceae?

2 Give an account of the vegetative organs of the Caryophyllaceae (excluding flowers and fruits), noting any adaptations to special habitats

3. Which members of the Caryophyllaceae grow in (*a*) hedges, (*b*) woods, (*c*) cornfields, (*d*) seaside localities, (*e*) sandy soil away from the sea?

4 Write an account of the structure and mode of pollination of the flowers in the British Caryophyllaceae.

5. Describe the typical fruit of Caryophyllaceae In what other family does a similar fruit occur, and how is it distinguished from Caryophyllaceae?

CHAPTER XX.

THE PRIMROSE FAMILY

468. In the **Primrose** (*Primula vulgaris*) note the thick stem which grows in the soil bears crowded bases of former leaves, together with numerous roots, and stores up reserve food, the pale green leaves, arranged in a rosette at the growing end of the stem, each being 3 to 6 inches long, obovate, toothed, wrinkled, with a broad midrib, veins very prominent on the lower side, which is hairy.

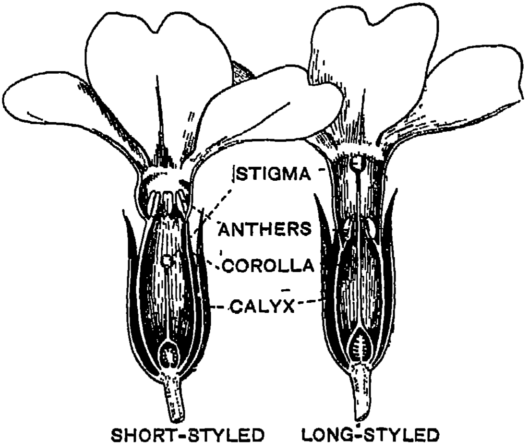


Fig. 130 —Vertical Sections of Short-styled and Long-styled Flowers of Primrose.

The flowers (Figs. 130, 131), each carried on a hairy pinkish stalk, appear to arise singly from the stem, but close inspection shows that they really form an umbel, since all the stalks are joined at the base to a short outgrowth from the stem. Note the bract on the flower-stalk, the inflated and five-angled calyx with five narrow pointed lobes, the corolla, consisting of a *tube* and a flat broad upper portion, the *limb* with five notched lobes The corolla-lobes are pale yellow, but round the mouth of the tube there is an orange-coloured ring with thickened folds, this ring is sometimes represented by five patches (one to each lobe) darker in colour than the rest of the expanded limb The limb serves as a platform on which the insect-visitors (chiefly bees) stand, and the orange ring acts as a honey-guide, enabling the insect to reach the centre of the flower more quickly and certainly.

Note the five stamens, which are, in some flowers, at the mouth of the tube, and can then be seen to stand opposite to the lobes, it is characteristic of the Primrose family (Primulaceae) to have the stamens equal in number to the corolla-lobes and opposite to (not alternate with) the lobes Open up the corolla-tube of a flower of this kind ("thrum-eyed") the filaments of the stamens are very short and are inserted near the mouth of the tube, while the stigma is about half-way up the tube Note the structure of the ovary it is one-chambered, and the numerous ovules are attached to a rod (placenta), which projects from the floor of the chamber upwards but does not reach the roof, so that the ovary-wall may be removed leaving the ovules attached to the free central placenta.

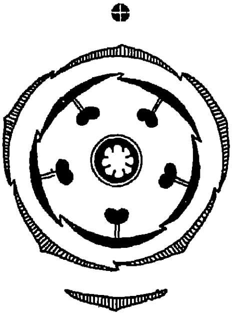


Fig 181 —Floral Diagram of Primrose.

Now examine other flowers on (1) the same plant which bears the kind of flower just described, (2) other plants Do you find that (1) *all* the flowers on the first plant are "thrum-eyed" (short-styled), (2) some plants have a different type of flower in which the *stigma* is at the mouth of the tube, while the stamens are inserted half-way up?—this is the "pin-eyed" or long-styled form The two kinds of flower appear to be always on distinct plants, and the plant apparently produces flowers of the same kind year after year. So that there are evidently two varieties of Primrose, differing only in the relative lengths of stamens and style, in the two types the positions of anthers and stigma are simply reversed In which case does self-pollination seem to be possible or likely to occur, and in which does it appear to be hindered?

Cover flowers of each kind with muslin, and find out whether self-pollination does occur in either kind With the microscope examine the pollen-grains and the stigma of each kind of flower, noting that the higher anthers (i e those of short-styled flower) produce larger pollen-grains (about $\frac{1}{700}$ inch diameter) than those of the long-styled flower (about $\frac{1}{1000}$ inch diameter); the long style is globular and rough with small projecting hairs, while the short style is rather flat-topped and smooth (with very short projections) Possibly the difference in size of the pollen-grains may be due to the fact that the larger grains have to send a longer pollen-tube down the long style to reach the ovary Perhaps also the longer stigmatic hairs are required to catch and hold the larger grains, which would tend to roll off the nearly smooth stigma of the short-styled flower

The fruit (capsule) of Primrose opens by five teeth (one opposite each sepal) at the top, each tooth being notched in the middle. This, together with the occasional production of "monstrous" flowers in which the pistil is represented by five leaves, affords evidence that the Primrose pistil is made up of five carpels.

469. In the **Cowslip** (*Primula veris*) the leaf-stalk is "winged" below the blade, not forming a bare midrib at the base of the blade as in Primrose The flowers are carried up on a general stalk or inflorescence-axis and are arranged in an umbel, each flower having a stalk of its own The corolla is smaller than in Primrose, the tube is shorter and its "throat" is dilated below the mouth, which is more funnel-shaped than in Primrose The orange-coloured honey-guides are very conspicuous, forming a patch opposite each of the five lobes. The flowers are heterostyled, as in the Primrose.

470. Note on Pollination of Primrose and Cowslip.—In both of these plants honey is produced at the bottom of the corolla-tube, and the flowers are visited largely, in fine weather, by bees, butterflies, and moths, whose tongues are long enough to reach the honey It has been found by experiment that, on the whole, "legitimate" cross-pollination (transference of pollen from long-styled flower to stigma of short-styled flower, and *vice versa*) yields better results (more seeds germinate and stronger seedlings are produced) than "illegitimate" cross-pollination, while both kinds of cross-pollination are better than self-pollination However, the manner in which the pollination of the Primrose actually occurs in nature has been for many years the subject of conflicting statements by various observers

The following extracts from a paper by Professor Weiss (*New Phytologist*, 1903), based on observations made in Shropshire during the Easter vacation of 1903, are given not merely because they are of interest, but in the hope that they may induce observers in various parts of the country to take up the subject.

The chief insects seen visiting the flowers were species of short-tongued burrowing-bees (*Andrena*), hive-bees (*Apis*), small humble-bees (*Anthophora*), large humble-bees (*Bombus*), and a fly called *Bombylius* (see Art 349). "Considering the regularity of the visits of *Bombylius* and the relatively large number observed in really fine weather, I have no doubt that this insect is an active agent in the pollination of the Primrose It seems admirably adapted to obtain nectar from the depths of the tubular corolla with its long proboscis, and it seemed at this time of year to confine its attention to the Primrose. Only on one occasion did I observe a *Bombylius* sucking nectar from the Celandine, which is so largely visited by the bees . . .

"On five different occasions I have observed *Bombus* visiting Primroses, and generally in such a manner as to ensure the pollination of the flowers In two cases, however, I noticed the humble-bee not sucking at the flower, but moving all over the corolla, apparently endeavouring to obtain the honey by illegitimate means, just as Darwin observed them at times biting through the corolla in the case of the Cowslip, of which they are regular visitors I ought to state clearly that *Bombus* was a more frequent visitor of other flowers than the Primrose, and was more commonly seen on the Willow, the Dandelion, the Violet, and the Barren Strawberry A smaller humble-bee, however, *Anthophora*, though less plentiful in the district, was more often seen on the Primrose, to which it seemed to confine its attention There can be no doubt that this insect is both able to gather honey from the Primrose flower and also to effect its pollination.

"The honey-bee, *Apis mellifica*, appeared to be less hardy than the humble-bee or *Bombylius*, for it only gathered honey on warm days and was not observed at all on several days when *Bombylius*, *Bombus*, and *Anthophora* were about The bees visited chiefly the Celandine, Barren Strawberry, Wood Anemone, Violet, and Dandelion Occasionally a stray one would visit a number of Primroses, but did not spend much time on each They were evidently endeavouring to obtain the nectar, which however they were unable to reach They stayed a little longer on the short-styled flowers, from which they collected a little pollen They were obviously not the regular visitors of the flowers, although they could no doubt bring about cross-fertilisation of the long-styled forms. This would also be effected by the visits of *Andrena* *gwynana*, but this insect must be placed in a different category from the bee, for it is a regular and busy visitor of the Primrose and more often seen by me on its flowers than on those of other plants. It was only observed towards the close of my visit when the weather was much milder, but then it was present in considerable numbers It gathered the pollen greedily and in getting at it poked its head deep into the mouth of the corolla

"From the instances given above, therefore, there is no doubt in my mind that Primroses are efficiently cross-pollinated in the district under observation by *Bombylius*, *Anthophora*, and *Andrena*, with the addition of occasional though by no means isolated visits of *Bombus*

"That self-pollination may occur fairly often in the Primrose cannot be denied, and, indeed, Darwin observed the frequent occurrence in both Cowslip and Primrose of Thrips, which he considered aided the self-fertilisation of both forms In many Primroses which I examined numbers of Thrips were present, and in these flowers it was very common to find pollen-grains scattered throughout the tube of the corolla and it seemed likely that it had been carried about there by these small insects Another agency for self-pollination is no doubt the wind, taken in conjunction with alterations in the position of the flower

"In the absence of cross-pollination, which must frequently fail in flowering plants in early spring, the strong winds of that season are probably of considerable use In the Primrose the flowers open at first in a vertical position, and if the flower is short-styled the pollen from the opening anthers can readily be shaken by the wind on to the lower-standing stigma But towards the end of flowering the flower-stalk has grown considerably in length and the flower passes into a horizontal and often a pendant position, so that the long-styled forms have a chance of self-pollination too when the flowers are agitated by the wind

"It may be thought that this movement is mainly for the concealment of the fruits, which in the Primrose are ripened beneath the foliage, but though this may be to a certain extent the case, I cannot but believe that the self-pollination is also a determining factor in this movement For in the Cowslip the very opposite occurs The flowers, at first pendant, offer greater facilities as far as self-pollination is concerned to the long-styled forms, but later on the flowers become erect and thus in the absence of cross-pollination the short-styled forms will have ample opportunity to be self-pollinated

"From the observations I have made on the Primrose I feel convinced that it is both regularly visited and cross-pollinated by insects under favourable climatic conditions, but that like most flowers adapted to the visits of insects it is provided with efficient means for self-pollination, and these are important to a plant flowering at so early a period of the year, when the visits of insects may be precarious"

Watch insects visiting the flowers of Primrose and Cowslip in the former case the flat top of the erect corolla serves as a platform, in the latter the insect enters the drooping flower from below. Why is the top of the corolla narrow and cup-like in Cowslip, instead of being broad and flat as in Primrose?

Why do Primroses usually grow in woods or on slopes and banks, while Cowslips grow mostly in open and level meadows, often among long grasses? Does the possession of a long flowering-axis in Cowslip, carrying up the flowers in a tuft, as compared with the arrangement in Primrose, seem to be connected with the different situations in which the two plants grow?

471. There are 3 other species of *Primula* in Brit. **Oxlip** (*P. elatior*), found chiefly in E. England, differs from Primrose in having flrs. in an umbel, scentless, K. less inflated, fl.-stalk shorter, capsule longer than K-tube (in Primrose it is just the same length). In these respects it resembles hybrids between Primrose and Cowslip, but differs in having the K. more downy, the flrs. paler, and no folds at mouth of C. The Cowslip differs from Oxlip in having shorter flr.-stalks, scented flrs., K-teeth blunt, C. more cup-like, capsule much shorter than K-tube. *P. farinosa* (**Mealy** or **Bird's-eye Primrose**), in bogs and hill-pastures in N. England and S. Scotland, has a rosette of short (1½ to 2 ins.) obovate leaves, smooth above, but with mealy white or yellow hair covering below, flrs. (June to Aug.) in a crowded erect umbel (stalk 2 to 8 ins.), C-lobes lilac with yellow mouth, flat (⅓ to ½ in. across), capsule twice as long as K. *P. scotica*, in N. Scotland, is like *P. farinosa*, but has K. shorter in proportion to C. and capsule shorter in proportion to K.

[Many species of *Primula* are cultd.; the Polyanthuses are varieties of Primrose with flrs. in an umbel, with mouth or edge of corolla-disc, or both, showing variegated colours, **Chinese Primrose,** with simple palmate leaves, **Japanese Primrose,** in which the axis grows out from centre of umbel and produces several umbles or circles of flrs. one above another, **Auriculas,** with smooth fleshy leaves.]

472. The Primrose Family (*Primulaceae*) is easily recognised by the regular flowers with stamens opposite to the corolla-lobes and the one-chambered ovary with free central placenta.

I. Ovary free (superior); capsule opening by teeth.
  A. Leaves all "radical."
    1. Corolla bell-shaped . . . [*Soldanella*].
    2. Corolla divided into tube and disc.
      (*a*) Corolla-tube narrow, funnel-shaped . . . *Primula*.
      (*b*) Corolla-tube inflated at middle . . . [*Androsace*].
      (*c*) Corolla-lobes bent back . . . [*Cyclamen*].

B Leaves carried on aerial shoots
 1 Corolla yellow *Lysimachia*
 2 Corolla white *Trientalis.*
C Submerged water-plant *Hottonia*
II Ovary free (superior); capsule opening by a lid
A. K and C 5-lobed *Anagallis.*
B K and C 4-lobed *Centunculus.*
III Ovary sunk in receptacle (semi-inferior) *Samolus*

Soldanella and *Androsace* are tufted Alpine plants, gen. with small fleshy or hairy leaves, as are also several species of *Primula*, they are often cultd. in rockeries. The other 8 genera named are repd. in Brit., but *Cyclamen* (often cultd.) is not really native, while *Centunculus* (Bastard Pimpernel) and *Trientalis* (Chickweed Wintergreen) are rare plants. Except in *Anagallis* and *Centunculus* the capsule opens by teeth.

473. *Lysimachia* has 3 common Brit. species. **Yellow Loosestrife** (*L. vulgaris*), beside streams, has a creeping rhizome giving off runners below ground, stems 2 to 4 ft. high, hairy, leaves opp., sessile, with black glands, 2 to 4 ins. long, ovate, flrs. (July, Aug.) in clustered cymes, dimorphic, C cup-shaped, ½ to 1 in. across, yellow with orange dots inside. **Yellow Pimpernel** (*L. nemorum*) and **Creeping Jenny** or **Moneywort** (*L. nummularia*) have the flrs. solitary in axils of leaves, and both are prostrate creeping hairless plants; the former has pointed leaves, very long flr.-stalks, star-like (rotate) corolla, with spreading pointed lobes, flrs. (May-July) 12-20 mm. across, the latter (a doubtful native, apparently not setting seed in Brit.), in moister places, has rounded leaves, flrs. (June-Aug.) larger, C cup-shaped, and sta. joined at base.

474. *Glaux* ("**Sea Milkwort**"), on sea-shore, a small plant with creeping rhizome giving off prostrate or erect shoots with crowded decussate small fleshy leaves (1 to 2 cms. long), flrs. (June, July) small (5 mm. across), in leaf axils, with white or pink cup-like 5-lobed calyx, but no corolla, sta. 5, alt. with K-lobes.

475. *Hottonia* ("**Water Violet**"), in pools, with creeping and floating or rooting stems, much-divided submerged leaves, flowering stems (1 to 2 ft.) erect, above surface, bearing whorls of stalked flrs. (May, June) with lilac corolla (2 cms. across) yellow at mouth; after flowering the stalks curve downwards.

476. Scarlet Pimpernel (*Anagallis arvensis*), a very common annual in fields, etc., has sessile decussate ovate leaves, stem 4-angled; flrs. (May-Oct.) solitary in leaf-axils, on stalks 1 to 2 ins. which curve down in fruit, corolla short-tubed and star-like, 5-lobed; sta 5 on base of C-tube **Bog Pimpernel** (*A tenella*) is perennial, more fleshy, smaller, flr. (June-Aug) has rosy funnel-shaped corolla with dark veins, filaments of sta joined at base, leaves smaller (3-6 mm) and more rounded

477. *Samolus* (**Brookweed**), in wet places, esp near sea and chiefly on S and W. coasts, has alt obovate leaves, gen with a "radical" rosette, stem 1 to 2 ft, erect, plant dies down in autumn, but young shoots formed in summer become rooted and replace parent plant; flrs (June-Sept.) in terminal, ½ to 1 in long, erect racemes, fl -stalk with a carried-up bract at the middle; flr 3 mm across, white, K and C 5-lobed; A 5 with short filaments, alternating with 5 scales (staminodes) which represent the outer whorl of sta missing in most Primulaceae; ovary semi-inferior, capsule 5-valved above the adherent "calyx-tube" (receptacle).

478. [*Cyclamen*, cultd., has a large starch-containing corm (bitter, but eaten by pigs in S Europe, whence the plant's name "Sowbread"); leaves radical, broad, stalked, flr on long erect stalk, curved down at top, C with short tube, thickened mouth, and 5 reflexed lobes; A 5, short, on base of C-tube, after flowering the stalk gen. becomes coiled, drawing the fruit down to the soil, or bending over and forcing fruit into soil.]

479. Flower Mechanisms in Primulaceae.—The pollination of Primrose and Cowslip has been dealt with The flowers are usually homogamous and honeyed, but in *Trientalis* they are protogynous and honeyless. Heterostyled dimorphic flowers occur in many species of *Primula* (though in *P scotica* and various garden Auriculas, etc, stamens and style are of same length), also in *Hottonia, Androsace,* Yellow Loosestrife (*Lysimachia vulgaris*), and *Glaux* (which also has cleistogamic flowers) In many cases, especially when the flower-tube is shallow or open, the flowers droop so that pollen and honey are protected The flowers of Scarlet Pimpernel open on bright days, usually from about 9 to 3, closing at night and in bad weather, if not cross-pollinated (by flies, etc) during the warm hours of the day, the flower is self-pollinated at evening when it closes and the stigma is rubbed against the stamens (the anthers open inwards in Primulaceae) The long-tubed forms are largely visited by bees and butterflies, the honey is secreted by a ring round the base of the ovary.

QUESTIONS ON CHAPTER XX.

1 Draw up a comparison between Primrose and Cowslip as to habitat, leaf, inflorescence, and flower

2 Describe the structure of a Primrose flower, pointing out the differences between the two types of flower.

3 Describe and discuss the pollination of the Primrose. Do you consider heterostyly plays an important part in promoting cross-pollination? Give reasons for your answer.

4 Describe the pollination of the Cowslip, and point out how it differs from the Primrose

5 Describe the fruit of Primrose and Cowslip.

6 Draw the floral diagram of a Primrose, and sketch in longitudinal section the two forms of the flower How do you account for the unusual position of the stamens in relation to the lobes of the corolla? How do you infer the number of the carpels?

7 Write notes on points of interest presented by Red Pimpernel, Sea Milkwort, Brookweed, Cyclamen

CHAPTER XXI.

THE DEAD-NETTLE FAMILY

480. White Dead-nettle (*Lamium album*) is common on roadsides, especially near houses, farms, and refuse heaps. It is a rather hairy plant, with a perennial creeping rhizome, which gives off (1) branches which grow horizontally in the soil, (2) branches which soon turn upwards and come above ground

The stems are square and hollow, the leaves arise from the flat sides of the stem in crossed pairs, those on the underground parts being small white scales. The aerial shoots are rooted and branched at the base, and then grow erect (6 to 18 inches high). The leaves are all stalked and heart-shaped, the lower ones having longer stalks and broader blades than the upper ones (why is this advantageous to a plant whose leaves are in superposed rows ?).

The flowers, produced all the year round, but especially in summer, are in ring-like clusters round the stem just above a pair of leaves, on the upper part of the shoot.

Examine several clusters and note that each consists of two groups of flowers, one group in the axil of each leaf; also that the central flower of each group is the oldest (the first to open), the next oldest being at either side of it, and so on. Each group is a biparous cyme which becomes uniparous after the first branching. This is obscured by the fact that the flowers are practically sessile, but it can be made out in Labiates whose flowers have distinct stalks, *e.g.* Calamint, Black Horehound. Fig. 132 is a diagram of a cyme (half-cluster), the main axis (1) ends in a flower and gives rise to

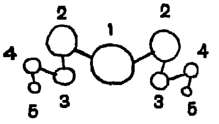


Fig. 132.—Diagram indicating the relation of Flowers in half of a cluster ("Verticillaster").

two lateral axes (2), each of which ends in a flower and then gives rise to a single axis (3), and so on How many flowers are there in each "ring" (2 cymes)? How do the upper "rings" differ from the lower ones as to number of flowers?

In a flower (Fig 133) note the almost regular calyx and the very irregular (zygomorphic) corolla The funnel-shaped calyx-tube has 5 nearly equal teeth, narrow and tapering, longer than the tube itself; it persists around the fruit The corolla-tube is curved, its lowest part is cylindrical, but higher up it is dilated and also flattened from side to side, while its mouth has an arched upper lip, two side-lobes, and a notched lower lip which spreads out. It is obvious that one of the calyx-teeth (sepals) is at the top or back of the flower, and since the 5 petals alternate with the 5 sepals, the lower corolla-lip represents a single petal, while the upper lip, though not divided, represents the two upper petals (some Labiates show this clearly).

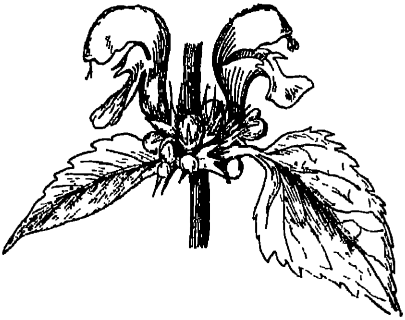


Fig 133 —Dead-nettle, showing two Clusters of Flowers.

The four stamens have long filaments attached to the corolla-tube, while the anthers lie under the hood-like upper lip. The two lower (anterior) stamens cross the upper pair, so that their anthers lie behind and above them. Note the hairy anthers, each with two lobes which, instead of lying side by side, are separated (owing to growth of the connective) and lie in a straight line one above the other Note the long style which runs up the back of the corolla-tube and is divided at the top into two fine stigmatic lobes.

Pull off (1) the corolla of a flower, (2) a whole flower, and carefully slit open the corolla-tube Note the ring of hairs near the bottom of the corolla tube; the constriction of the tube just below this ring, the four-lobed ovary with flat upper surface, the style arising from between the four lobes, which are separated from each other by deep grooves; the ring-like nectary around the base of the ovary, better developed on the lower than on the upper side (Fig. 134). The ovary consists of two carpels, upper and lower, but early in its development the ovary divides into four parts, each nearly independent of the rest, each chamber contains a single ovule.

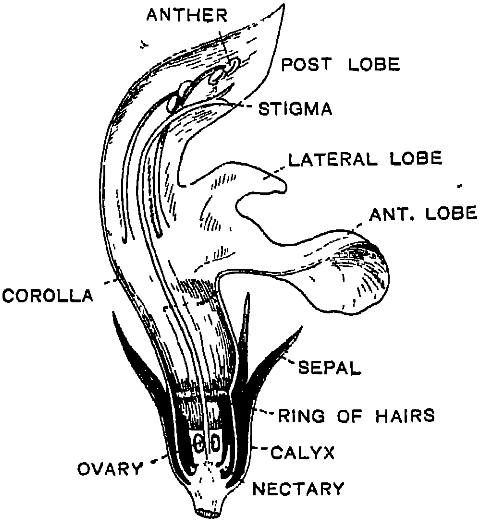


Fig 134 —Sectional Elevation of Flower of White Dead-nettle.

The upper lip of the corolla forms a protecting hood (why is this necessary?), the lower lip a platform for the humble-bees which are the chief visitors to White Dead-nettle flowers.

The ring of hairs inside the corolla-tube above the ovary stops small insects from crawling down to the nectary, besides keeping rain from trickling down and spoiling the honey. The flower is homogamous, and capable of self-pollination, but the forked style-tip hangs down and touches the bee's back before the anthers do, so that cross-pollination must occur regularly.

The corolla (with the epipetalous stamens) and the style fall off very soon after pollination has taken place, and the four ovary-chambers grow into smooth black akenes ("nutlets") with hard coats, each nutlet is three-sided and flat-topped As they ripen they become loose and fall out of the persistent calyx-tube, or are shaken out by wind.

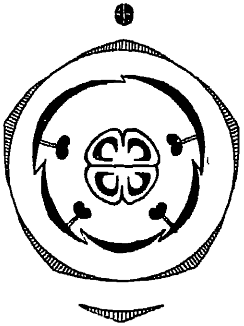


Fig 185 —Floral Diagram of Labiatae.

481. Red Dead-nettle (*Lamium purpureum*) is far more abundant and widely distributed than the White, often occurring in extensive patches in cultivated soil (fields, gardens) as well as on waste ground. It is a smaller plant and is annual, flowering throughout the year (chiefly from April to October), and may pass through several generations in a single year Its leaves are broader in proportion to their length, with a more heart-shaped blade, and are more crowded towards the top of the stem The upper leaves are often densely covered with silky hairs, and have a purplish-red colour

In open places the plant is branched at the base, giving it a spreading habit, rarely over 6 inches high, and the whole plant (stem, leaves, flowers) is deeply coloured. When growing among rank and crowded vegetation the plant is less branched and taller, with dull-green leaves and stems In hedgerows the plant is "drawn" up to a height of 18 inches or more (why?), the stem having long internodes, and having nearly all the leaves at the top.

The flowers are smaller than those of *L album*, but similar in structure. The corolla is about ½ inch long, so that short-tongued bees, and even flies, can reach the honey and effect cross-pollination, the tube is not constricted below the ring of hairs, which is often poorly developed, and the throat of the tube is very wide from back to front.

482. Two other Brit. species of Dead-nettle are fairly common. *L. galeobdolon* **(Yellow Archangel)**, perennial, in woods and shaded hedgerows, apart from being a shade-loving plant and having yellow flowers (April-June), resembles *L. album* in habit and structure. Its leaves are relatively longer and narrower, the calyx has short teeth, the lower lip of the corolla has red or brown spots (making the flr. more conspicuous to bees), and the anthers are hairless. [**Spotted Dead-nettle,** *L. maculatum*, a garden-escape, is probably a cultd. variety of *L. album*, with a broad white streak down the middle of the leaf, with white spots gen. at each side of it, and pale-purple flrs.]

Hen-bit Dead-nettle (*L. amplexicaule*), annual, in waste places and cultd. fields, is like *L. purpureum* in general habit, but its leaves are gen. distinctly lobed, and the upper ones are stalkless and clasp the stem; it rarely grows in such crowded patches, and flowers freely from April to Oct., the pale-rose flrs. varying in size; in spring and autumn small flrs. are produced which have a small imperfect corolla and do not open but are self-pollinated (cleistogamic flrs.), the ordinary flrs. being pollinated by bees.

483. The Dead-nettle Family (*Labiatae*) is one of the most easily recognised, all the Labiates having square stems, simple decussate leaves without stipules, corolla generally two-lipped with no clear indication of the separate petals, stamens generally in two pairs owing to suppression of the upper one (sometimes only two stamens present), ovary of 2 carpels, but with four one-seeded chambers. By the ovary and fruit (four akenes) Labiates are distinguished from those plants of the Foxglove Family which have square stems, decussate leaves, and bilabiate flowers with two pairs of stamens. By the decussate leaves, bilabiate corolla, and the presence of four stamens Labiates are distinguished from the Borage Family, in which the ovary and fruit are similar in structure.

I. Ovary chambers separate to the very base.
- A. Stamens 2, with long connectives *Salvia*
- B. Stamens 4, the upper pair longer *Nepeta*
- C. Stamens 4, the lower pair longer

1. Stamens spread out and project from C-tube.	
(a) Corolla regular or nearly so	
(i) Flower with 4 perfect stamens	*Mentha.*
(ii) Flower with 2 perfect stamens	*Lycopus.*
(b) Corolla 2-lipped	
(i) Plant tall, erect, K 5-toothed	*Origanum.*
(ii) Plant low, creeping ; K 2-lipped	*Thymus.*
2. Stamens (4) come together below upper C-lip, K-tube with 13 ribs	
(a) C-tube straight, upper lip flat	*Calamintha.*
(b) C-tube curved, upper lip concave .	[*Melissa.*]
3. Stamens (4) parallel or nearly so ; K-tube with 5 or 10 ribs or veins	
(a) K inflated, flower large .	*Melittis*
(b) K tubular, C-tube short .	*Marrubium.*
(c) K 2-lipped, closing over fruit.	
(i) Upper K-lip flat, filaments forked .	*Prunella*
(ii) Upper K-lip pouched ; filaments simple	*Scutellaria.*
(d) K 5-toothed, funnel-shaped, teeth generally spreading	
(i) Anthers hairy (exc. Yellow Archangel)	
(α) Nutlets with flat top ...	*Lamium.*
(β) Nutlets with round top	*Galeopsis.*
(ii) Anthers not hairy.	
(α) K-teeth broad and blunt .	*Ballota.*
(β) K-teeth narrow and sharp .	*Stachys.*
II Ovary chambers joined at least halfway up	
A Upper C-lip entire or slightly notched	*Ajuga.*
B. Upper C-lip deeply cleft .	*Teucrium*

484. Wild Sage or **Clary** (*Salvia verbenaca*), fairly common in dry fields and waste places, 1 to 2 ft high, with woody rhizome, oblong wrinkled leaves (2 to 4 ins.), flrs. blue-purple (June-Sept) in cymes of 3 on a long "spike." See Art 500 for mechanism of flr. *S pratensis*, very rare, has large herm flrs and smaller ♀ flrs [*S officinalis* and other species are often cult. So is the allied *Monarda* ("Oswego Tea") which has bright-red flrs.(long-tubed) and bracts and calyx coloured.]

485. Ground Ivy (*Nepeta*), in hedgerows, etc , has perennial stems 6 to 18 ins. long, rooting at the nodes and giving off erect flowering shoots about 6 ins high, leaves kidney-shaped, crenate, all stalked; cymes with 1 to 3 flrs (March-June), K-teeth short, recurved; C blue-purple with purple and white spots, upper lip straight and notched; smaller ♀ flrs. occur besides the larger herm. flrs., gen. on separate plants.

486. [*Ocimum basilicum*, Sweet Basil, and other species of *O.* are cultd. as pot-herbs; *Coleus* is cultd. in greenhouses for its brilliantly coloured and variegated leaves, the finest kinds being varieties and hybrids obtained by artificial cross-pollination; in both genera the sta. lie on the flat lower C-lip.]

487. The commonest Brit. species of *Mentha* is **Water Mint** (*M. aquatica*), 1 to 5 ft. high, in wet places, gen. covered with soft hairs; creeping rhizome giving off numerous runners ("suckers"); leaves stalked, ovate or cordate, serrate; flrs. (July-Sept.) small, pale lilac, in dense clusters; C-tube short, mouth with 4 nearly equal lobes and with hairs which protect the honey; A 4, equal, spreading, anthers hairless with parallel lobes. **Corn Mint** (*M. arvensis*), in cultd. fields and waste places, has flrs. very hairy without and within, of 2 kinds (larger herm., small ♂). **Pennyroyal** (*M. pulegium*) has very small leaves with almost even edges; **Peppermint** (*M. piperita*), not very common, probably a form of Water Mint, has few or no hairs. **Horse Mint** (*M. sylvestris*) and Round-leaved Mint (*M. rotundifolia*), both rather rare, are very hairy plants with *sessile* leaves; **Spear Mint** (*M. viridis*), the kind chiefly grown in gardens, is like these, but hairless or nearly so.

488. *Lycopus* (**Gipsywort**), like the Mints, grows in wet places, esp. by streams, 1 to 3 ft. high, gen. hairless; leaves oblong, toothed or pinnate-lobed; flrs. (June-Sept.) small, crowded; K and C with 4 or 5 equal teeth, C bluish white with purple dots, hairy inside; 2 lower sta. long with anther-lobes parallel, 2 upper antherless; stigmas *flat*.

489. Wild Marjoram (*Origanum*) in dry fields and copses, esp. on limestone, has a short rhizome; shoots 1-3 ft.; leaves ½ to 1 in., ovate, hairy below; flrs. (July-Sept.) small, purple, each with a green or purple bract ¼ in. long (as long as K) below it; larger flrs. herm., protandrous, with 4 long sta. (lower pair projecting beyond C); smaller flrs. ☿, paler, opening before the others.

490. Thyme (*Thymus*) abundant on dry slopes and on hills, is a small wiry much-branched plant with woody rhizome, small (3-6 mm.) ovate entire leaves; flrs. (June-Sept.) purple or white, in small cymes (gen. 3); K purplish; A 4, gen. projecting beyond C; some flrs. herm., others ♂, others ♀, on same or different plants.

491. *Calamintha* has 3 Brit. species, none very common, in dry and rocky places; **Hedge Calamint** (*C. Clinopodium*) is the commonest and has red-purple flrs. (July-Sept.); the Calamints are all covered with soft hairs, and the calyx has 13 ribs; the cymes are gen. loose, the flrs. being stalked (esp. in *C. officinalis*), the sta. (upper pair sometimes antherless) gen. have the anther-lobes separated by a broad connective (transition from ordinary Labiate sta. to the T-shaped sta. of *Salvia*).

492. Balm (*Melissa*), found as a garden-escape, is allied to Calamint; the sta. do not project from flr., but lie under the concave upper C-lip; C ½ in. long, white. **Bastard Balm** (*Melittis*), in woods and hedgerows in W. and S. England and Wales, has large white flrs. (May-July), solitary or 2 or 3 in leaf-axils; K wide open; C 1 to 1½ ins. cream-white with pink or purple spots. **White Horehound** (*Marrubium*), native only on the S. coast of England, in waste places; 1 to 2 ft. high, with short rhizome; leaves leathery, wrinkled, woolly, stalked; flrs. (July-Nov.) in dense cymes, small; K with 10 short spiny hooked teeth; C ½ in., white.
Black Horehound (*Ballota*) also has downy wrinkled leaves, but its flrs. (July-Aug.) have the K-teeth (5) spreading and the C red-purple, and the plant has a disagreeable smell.

493. Self-heal (*Prunella*), common in damp meadows, is a hairy plant with creeping rhizome; stems 3 to 12 ins. high; leaves stalked 1 to 2 ins. long, ovate or oblong, uppermost ones (below the short compact "spike" of infls.) sessile; pairs of cymes close together, each gen. with 3 short-stalked flrs. in axils of broad leaves with purple edges; flrs. (June-Sept.) gen. rich purple; C-tube with a basal ring of hairs inside, upper lip concave, lower lip 3-lobed; each sta. is forked at top, lower fork bearing an anther, upper fork bare; small ♀ flrs. occur besides the larger herm. flrs.; calyx closes over fruit and is directed upwards when the air is dry, but opens and stands horizontal in moist air, the seeds being dispersed in wet weather.

494. Bugle (*Ajuga reptans*) is rather like Self-heal in general habit and in habitat, but its flrs. (April-July) are blue-purple, in longer "spikes" (3 to 8 ins.), the K does not close over the fruit, the C has a *very* short upper lip (how, then, is the flr. protected against rain?), beyond which the 4 sta. project (filaments not forked).

495. The 2 **Skullcaps** (Greater, *Scutellaria galericulata*, and Lesser, *S. minor*) grow in moist places, the Lesser often on heaths; the Greater Skullcap, 6 to 18 ins. high, has long ovate leaves (1 to 2½ ins.), flrs. (July-Sept.) single or in pairs; C blue, 15 mm. long, with curved tube and short lips, sta. and style below upper lip; *S. minor* is a smaller plant (4 to 6 ins.), more slender, more branched, leaves ⅓ to 1 in. long; flrs. 8 mm. long, pale lilac.

496. Hemp-nettle (*Galeopsis*) has 3 species in Brit., in cornfields and waste places; *G. tetrahit*, the commonest, 1 to 3 ft. high, has a large swelling on the stem below each pair of leaves; when the stem is beaten down by rain or wind these swellings curve so as to bring the stem erect again (as in wheat, etc.); leaves 1 to 4 ins. long, stalked, coarsely toothed; stem and leaves have long stiff hairs; flrs. (July-Sept.) crowded, gen. purplish red; no hairs inside C-tube; anther-lobes lie side by side (inner lobe hairy, outer larger and hairless).

497. *Stachys* has 4 common Brit. species, **Wood Betony** (*S. betonica*) has its cymes of bright red flrs (June-Sept.) in a short head (1 to 3 ins. long) at top of stem, but the others have the flrs. in long "spikes"; *S. sylvatica* **(Hedge Woundwort),** 1 to 3 ft. high, stem solid and slender, leaves 2 to 3 ins. with long stalks, flrs. (June-Sept.) purple red, lower C-lip with white spots; **Marsh Woundwort** (*S. palustris*) in wet places, is smaller, with stout hollow stems, less hairy, leaves much narrower, flrs. paler; **Field Woundwort** (*S. arvensis*), in cultd. fields and waste places, is annual, branched at base, with small (½ to 1 in.) leaves, C = K in length (8 mm.) and is pink.

498. Wood Sage (*Teucrium scorodonia*), very common in dry and stony places, with creeping woody rhizome giving off numerous "suckers", stems 8 ins. to 2 ft. high, much branched, leaves stalked, ovate, greyish, wrinkled, 1 to 1½ ins. long, pairs gen. spaced out on stems, flrs. (July-Oct.) in racemes 3 to 6 ins. long (1 flr. in axil of each leaf in upper part of stem), flrs. short-stalked, all facing one side (towards the strongest light), K-tube bulged at base, upper tooth larger than the 4 lower; C pale yellow (straw-coloured), tube short, 2 upper lobes very small, 2 side lobes larger, lower lobe largest, rounded and concave, sta. and style project from flr. between upper C-lobes, anthers purple.

499. [**Lavender** (*Lavendula vera*) cultd. for its perfume, is shrubby, 2 or 3 ft. high, with narrow leaves rolled back at edges, flrs. small, greyish blue, in "spikes" of cymes; sta. 4. **Rosemary** (*Rosmarinus*), also shrubby with rolled leaves (stomates in hairy grooves on underside); flrs. with purplish K, pale blue 2-lipped C, 2 sta.]

500. Flower Mechanisms in Labiatae.—In most Labiates the flower is protandrous, and in many cases the stamens move outwards or downwards (well seen in Wood Sage) after the anthers have opened, when the style moves into their place and the stigmas spread apart to receive pollen. When the flower is homogamous, the style projects below the anthers so as to be touched first by the visiting insect. In the short-tubed flowers of Mint, Gipsywort, Thyme, and Marjoram, with more or less regular corolla and spreading stamens, all sorts of insects crawl over the flowers and touch the anthers and stigmas with any part of their bodies.

Most British Labiates, however, are definitely "bee-flowers" and have a conspicuous lower corolla-lip to attract insects and to act as a landing-place, and usually an arched upper-lip to shelter the stamens and style, which are generally placed so as to touch the bee's back as it enters the flower.

In Sage (*Salvia*) the two stamens (the other pair is represented by small staminodes) have a peculiar structure, they are T-shaped, the filament being short and jointed to the long connective. In the lower types of *Salvia* each end of the connective bears a half-anther, but in the higher types (*e g.* Garden Sage, which should be examined) the lower end of the connective is barren and flattened and the outer (upper) part of the connective is longer than the inner (lower part), the whole forming a delicate lever. A bee on entering the flower (Fig 136) pushes against the united lower ends of the two connectives, in poking for the honey, and causes the curved connectives to swing on the filaments as on hinges, so that the two fertile anther-lobes (*a*) come down and strike the bee's back, dusting it with pollen. As the bee retires, the stamens return to their former place under the corolla-hood. In an older flower the style bends down and the stigma is touched first by a bee entering the flower.

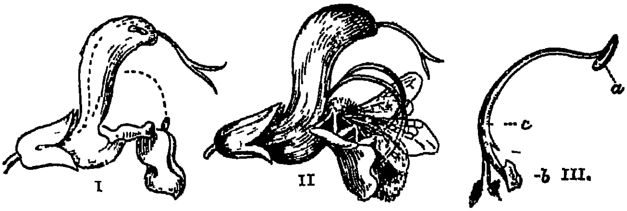


Fig 136.

I, Flower of Sage from side, II, With Humble-bee extracting Nectar, and the Anthers rubbing against his back, III, Single Stamen.

[The long-tubed red flowers of *Monarda* are largely visited by butterflies, and some tropical species of *Salvia* are pollinated by humming-birds.]

Cross-pollination is promoted by the occurrence, often on different plants, of pistillate flowers besides the ordinary flowers, as in Thyme, Ground Ivy, Corn Mint, Self-heal.

QUESTIONS ON CHAPTER XXI.

1 Describe the typical inflorescence of Labiates, as see nettles

2 In what places would you expect to find White Dead- Dead-nettle, Yellow Dead-nettle, Thyme, Bugle?

3 Point out as many differences as you can between Whi Dead-nettles

4 Draw a floral diagram of the Dead-nettle flower Do consist of one or of more petals? Give reasons for your an

5 Describe the pollination of Dead-nettle or of any ot flower you have observed

6 Describe the structure and mode of pollination of th Sage (*Salvia*)

7 Describe the flowers of Mint, Self-heal (*Prunella*), Sage (*Teucrium*), pointing out in each case how they di Dead-nettle flower

8 Mention Labiates whose flowers are pollinated by (*b*) short-tongued bees, (*c*) long-tongued bees

CHAPTER XXII.

THE FOXGLOVE FAMILY (SCROPHULARIACEAE)

501. Foxglove (*Digitalis purpurea*), the most familiar and most conspicuous British plant of this family, is abundant in sandy or rocky soils in open places or the edges and less shaded parts of woods It is usually biennial, forming in its first year a rosette or broad-stalked "radical" leaves with prominent veins and wrinkled surface, 6 to 12 ins long, in the second year the stem grows up to form a flowering shoot, 1 to 5 ft high, with spaced-out leaves gradually becoming smaller and sessile In sheltered places especially, the plant becomes perennial, as do also the garden varieties.

The plant may send up branches when the flowers of the main shoot are nearly over, or in cases where the main stem has been damaged, these branches are quickly formed if the main stem is cut off either near the base or below the flowers

Note the arrangement of the flowers in a long raceme, with a small leaf (bract) below each flower. The young flower is erect, but before opening it begins to droop owing to the bending downwards of the short stalk. The flowers are arranged spirally on the stem Do they spread out in all directions when open? If not, how are they brought into their final position, and why? Note the calyx, deeply cleft into five lobes, the uppermost narrower than the others.

Sketch (1) a complete flower in side view, (2) the parts seen on looking into the mouth of the corolla, (3) the isolated corolla (pulled away from flower) in side view, (4) isolated corolla slit open along the middle line above, (5) the pistil and nectary, with calyx removed, (6) a section of the entire flower (Fig 137) Note the peculiar form of the corolla·

why is the tube dilated at the base, then widened out? Why is the mouth of th

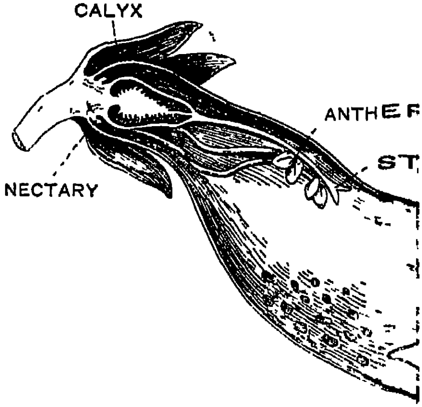


Fig 187 —Longitudinal Section of Flower of Fox

below than above? Note the two lobes of (= 2 petals) and the less distinct lobing of th lip (= 3 petals)

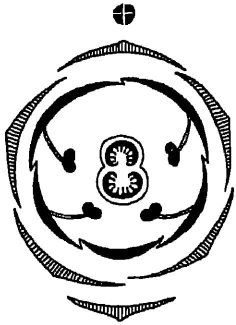


Fig 188 —Floral Diagram of Foxglove

If you watch humb the flower, you sho answer the followi What are the uses of ing position of the f curious "eye-spots" (3) the hairs inside Examine flowers of the anthers of the stamens shed their those of the lower stigma-lobes separate to receive pollen; sequence of events pollination? Note anther-lobes diverge when the anther ripens. ovary and note the two chambers, with num the axile placenta, which resembles a dumb-bell in cross-section (Fig. 138)

The egg-shaped capsule opens by splitting on each side, the partition splits into two layers, and at the same time separates from the placenta, so that the two valves are formed and the numerous small seeds are left on the placenta and are gradually shaken off when the wind rocks the plant (censer-mechanism) Note that the upper valve of the capsule splits down the middle, sketch the ripe capsule before and after opening

502. Speedwell (*Veronica*). There are 16 British species of *Veronica*, of which 10 are common and widely distributed. In certain respects they all agree: the leaves, or only the upper ones, are opposite, the flowers small and blue, with 4-lobed calyx and corolla, the corolla-tube being very short and the lobes flat, stamens 2, projecting from the corolla along with the style which ends in a small stigma

Germander Speedwell or "Bird's-eye" (*V chamaedrys*), one of the commonest species and earliest to flower (April to September, but chiefly in May and June), has rather large flowers (½ in across) and will serve as a type It is perennial and has slender branches, 8 to 24 ins long, prostrate at the base but soon becoming erect.

Note the two opposite lines of hairs on the stem (cf Chickweed); the opposite leaves, sessile or nearly so, ½ to 1½ ins. long, cordate (heart-shaped), with deeply toothed margin and wrinkled hairy surface

The flowers are in racemes, each of which arises in the axil of one of the upper leaves, and is carried well up on a slender axis; the raceme with its stalk is 2 to 6 ins long. Each flower arises in the axil of a narrow pointed bract, these are arranged spirally on the raceme axis, not in crossed pairs like the foliage-leaves.

Note the calyx, deeply divided into four narrow green pointed lobes. The short flower-stalk is slightly curved, so that the flat spreading lobes of the corolla lie in a vertical plane, what advantage do you see in this? The plant commonly grows on hedgebanks, in which case the flowers all tend to face outwards (why?); when in open places, the flowers face in different directions all round Note the four lobes spreading from the short tube of the bright-blue corolla, the two side lobes, which lie behind (below) the upper lobes, are similar in size and shape—the upper lobe is the largest, the lower lobe is the narrowest

Note the white rim (honey-guide) at the mouth of the corolla-tube and the hairs which protect and partly conceal the honey, secreted by a ring-like nectary round the base of the ovary

The position of the lobes of the calyx and corolla suggests that the uppermost (posterior) sepal of the calyx is missing, and that the upper petal represents the two upper petals usually found in this family, occasionally one finds Speedwell flowers with five sepals and five petals The two stamens present belong to the upper pair, each is inserted on the corolla-tube between the upper petal and one of the side petals The ovary is two-celled, each cell having numerous ovules on an axile placenta, and is broader than long (flattened from side to side), covered with hairs, and notched at the top, the style arising from the notch.

The flowers are largely visited by hoverflies (Art. 349), and appear to be specially adapted for cross-pollination by these insects. The two stamens project horizontally and diverge a little at each side; the filament of each stamen has at its base a small bend which forms a kind of hinge, the style hangs out over the lowest petal A fly coming to the flower first rubs its underside against the stigma, and then grasps the stamens with its legs and draws them together to form a support as it probes for honey in the corolla-tube, thus causing the anthers to dust its body with pollen. When the insect leaves, the stamens spring back to their former position, and the flower can be visited several times. Do you see why the corolla has no "platform" lower lip?

The sepals persist around the short flattened capsule and grow a little longer after pollination. The ripe capsule, which contains rather few seeds in each chamber, opens by two slits, but the valves remain attached to the seed-bearing axis The seeds are thin, flat on one side and convex on the other, they escape gradually through the narrow slits; the sepals also help in this censer-mechanism and prevent too many seeds from falling out together except when a strong wind is blowing After flowering the racemes lengthen considerably this aids in the dispersal of the seeds by wind (how?), the flower-stalks stand erect, close to the raceme axis, while the flowers are young, spread out when the flowers open, and become erect again when the flowers have been pollinated.

503. Most of the other common Speedwells have smaller flowers, also visited chiefly by flies, but often self-pollinated—especially where the flowers are very small and inconspicuous. The following notes will help in the identification of the commoner Brit. species.

Flrs. solitary in axils of alternate foliage-leaves (lowest leaves, without flrs., opposite), seeds cup-shaped or deeply grooved on one side.—*V. agrestis* (**Procumbent Speedwell**), in waste places and cultd. soil; leaves serrate, about as long as the flr.-stalks, flrs. (Feb.-Sept.) pale blue, sepals ovate, C 4-8 mm. across, capsule flat, lobes 4- to 10-seeded. *V. buxbaumii*, in fields, is similar but has flr.-stalks longer than leaves, flrs. bright blue, sepals lanceolate, C 12 mm. across. *V. hederaefolia* (**Ivy Speedwell**), in cultd. soil, has broad leaves with 5 to 7 rounded lobes, capsule-lobes globular with 1 or 2 seeds, sepals cordate, longer than C, C 4 mm. across, pale blue. All three are annuals.

Flrs. in terminal racemes.—*V. arvensis* (**Wall Speedwell**) in dry sandy places, annual; stem with 2 opp. lines of hairs; leaves downy, flrs. (Apr.-Sept.) very small, pale blue, sepals narrow, longer than C, style very short, capsule 3-6 mm. broad, shorter than sepals, each lobe with 6 or 7 flat seeds. *V. serpyllifolia* (**Thyme-leaved Speedwell**), in moist fields and waste places, perennial, has stem hairy all round, leaves sessile, nearly entire, flrs. (May, June) in long (1 to 4 ins.) racemes, C white or lilac, longer than sepals, 6 mm. across, capsule shorter than sepals, style as long as capsule. *V. spicata*, only on chalk in E. England and limestone in W. England and Wales, a hairy perennial, has stout erect stems, 6 to 18 ins., leathery oblong leaves, 1 to 1½ ins., flrs. (July, Aug.) in a dense spike 2 or 3 ins. long, bright blue; C 6 mm. across, with cylindrical tube (exceptional in *Veronica*) and narrow lobes, sta. and style very long.

Flrs. in axillary racemes, plants perennial.—*V. chamaedrys* has been described. *V. officinalis*, in similar habitats, has stem hairy all round, leaves with a short stalk, flrs. (May-July) pale blue or lilac, C 4 mm. across, style very long, capsule narrow, much longer than sepals. *V. scutellata* (**Marsh Speedwell**), in bogs, etc., has hairless stems and leaves, leaves sessile, lanceolate; flrs. (June-Aug.) white or pinkish, C 6 mm. across, capsule small, deeply lobed; flr.-stalks as long as leaves (1 to 2 ins.), bent down in fruit.

In all the preceding species the capsule-valves remain attached to the seed-bearing axis, but in the following 2 species they become detached, and the capsule is flat, circular, and only slightly notched. *V. beccabunga* (**Brooklime**), beside streams, has hollow stems, rooting below, spreading branches, 1 to 2 ft. high; leaves stalked, oblong or obovate, serrate, 1 to 2 ins. long, flrs. (May-Sept.) in racemes 2 to 4 ins. long, bright blue (sometimes pink); sepals small, C 4 mm. across;

seeds swell up in water (seed-coat gummy), and capsules open in wet weather *S anagallis* (**Water Speedwell**), also in wet places but not so common, has stems 1 to 3 ft., not much branched; leaves 2 to 5 ins., sessile, lanceolate, flrs (June-Aug) in racemes 4 to 12 ins long, pale lilac or white, C 4 mm across, capsule shorter than sepals, seeds as in *V beccabunga*

Note that the 3 last-named species, found in wet places, differ from most other Speedwells in being hairless plants What other water-loving plants are hairless? What water-loving plants form exceptions to the general rule in this respect?

[Several shrubby foreign species of *Veronica*, with leathery decussate leaves, are cultd in gardens and shrubberies; their flrs have the typical Speedwell structure, but in some species the C-tube is long]

504. The Foxglove Family (*Scrophulariaceae*) shows a fairly wide range of flower structure, as we have seen from our study of Foxglove and the Speedwells, but all agree in having the flower zygomorphic (in some cases nearly regular), with gamosepalous calyx (sometimes almost polysepalous), a gamosepalous and typically two-lipped corolla; stamens generally in two pairs, epipetalous, a honey-disc at base of ovary, a two-chambered ovary (chambers in vertical plane of flower) with numerous ovules (few in *Veronica*) on axile placentas.

The Scrophulariaceae are classified as follows —

I. Corolla with upper lobes external (covering the lateral ones) in the flower bud

  A Leaves alt., corolla reg or nearly so, 5-lobed . *Verbascum*, [*Celsia*]

  B Lower leaves at least opp, 5th sta. absent or repd by a staminode; corolla bulged or spurred at base *Linaria*, *Antirrhinum*, [*Calceolaria*, *Alonsoa*, *Maurandia*, *Diascia*, *Nemesia*]

  C Like B, but corolla not bulged or spurred . *Scrophularia* [*Mimulus*, *Chelone*, *Pentstemon*, *Collinsia*, *Torenia*, *Paulownia*]

II. Corolla with upper lobes or lip covered in bud by one or both of the lateral lobes.

  A Corolla-lobes all flat and diverging, or upper 2 erect *Digitalis* *Veronica*

  B Corolla with 2 upper lobes forming a hood *Melampyrum* *Pedicularis*, *Bartsia*, *Rhinanthus*, *Euphrasia* These are al parasitic on roots of grasses

505. *Verbascum* (Mullein) has 2 common Brit species, besides varieties and hybrids **Woolly Mullein** (*V thapsus*) is a stout erect biennial, 2 to 5 ft high, on banks and roadsides, with a dense covering of woolly hairs, oblong pointed leaves narrowed at base into 2 wings running down the stem, flrs (June-Sept) in a long dense spike (1 ft or more), C yellow, 15-25 mm across, with 5 spreading lobes, A 5, the 3 upper ones shorter and with white or yellow hairs on their filaments, capsule as in Foxglove **Dark Mullein** (*V nigrum*), not so common, smaller, much less hairy, has its lower leaves long-stalked, flrs (June-Oct) in clusters in axil of each bract, 12-20 mm across, filaments of all 5 sta with purple hairs [*Celsia* (Dwarf Mullein) has wheel-shaped 5-lobed corolla, like *Verbascum*, but 4 stamens only, in 2 pairs]

506. *Linaria* (**Toadflax**) has 1 common Brit species (*L vulgaris*) in hedges, etc , with a short rhizome, giving off erect shoots (1-2 ft), with crowded hairless narrow leaves; flrs (July-Oct) in a dense raceme, yellow, K 5, small, C-tube 23 cms long, with long pointed spur at base on lower side, upper lip 2-lobed, lower with a projecting orange-coloured "palate" or pouch closing the mouth and lined with hairs inside, sta in 2 pairs, arising from base of C-tube, capsule opening at the top Abnormal ("peloric") flrs sometimes occur with reg corolla (5 lobes at mouth, 5 spurs at base) and 5 sta

[**Ivy-leaved Toadflax** (*L cymbalaria*) is an introduced plant, though common on walls; it is perennial and has long creeping stems, ivy-like leaves (12 20 mm broad), and axillary long-stalked flrs (May-Sept), 8 mm. long, C lilac, with yellow "palate" and short spur, capsule opens by 3-toothed valves, after pollination the flr-stalk turns from the light and forces the capsule into dark crannies in the wall]

507. *Antirrhinum* (**Snapdragon**) has 1 Brit species (in Eng only), *A orontium*, annual, in cornfields, etc., with rose-purple flrs (July-Oct), 10 mm long Examine a cultd. form, note the almost free K-lobes, the C as in *Linaria*, but compressed below and with a blunt pouch instead of a spur, the lopsided ovary, the very distinct nectary, the capsule opening by 3 pores at top (1 pore on upper chamber, 2 on lower)

508. [In *Calceolaria* note the bladder-like lower C-lip and the 2 sta In *Alonsoa* (Mask Flower) the leaves are opp or in 3's, the C-tube very short with 2 lips, and the 4 sta are exserted *Nemesia* is allied to *Linaria*, but has a flat capsule *Maurandia* is a greenhouse climber with sensitive twining petioles (cf. *Clematis*) and flr like Snapdragon, but no pouch at base of C-tube. In *Diascia* the C-tube has 2 spurs]

509. *Scrophularia* (**Figwort**) has 2 common Brit species, erect herbs with 4-sided stems, decussate leaves, and dull purplish flrs. in axillary cymes; *S nodosa* is 2-3 ft high, with short rhizome bearing tubers, while *S aquatica*, in moister places, is taller, less branched, and bears no tubers on the rhizome, while the erect stem has its angles winged. The flrs (July-Sept) have the posterior sta. repd by a scale, for pollination, see Art 517, C 5-lobed, the 2 upper erect and forming an upper lip, the 2 lateral shorter, the lowest turned downwards.

510. [*Mimulus*, of which several species are cultd , esp the **Musk** (*M moschatus*), has opp leaves , K 5-angled, C 2-lipped, stigma-lobes flat and spreading, but sensitive and closing when touched on inner surface *M luteus* (**Monkey Flower**) occurs in wet places, esp by streams, in Brit , but is a garden-escape]

511 [In *Pentstemon* (**Beard-tongue**) the flr has a long staminode (= posterior sta , of *Scrophularia*) , *Chelone* (**Turtle-head**) has the sterile 5th sta shorter than the fertile ones *Collinsia* has K deeply cleft and otherwise resembles Snapdragon, but the C-tube is bulged on the *posterior* side , *Torenia*, an allied genus, has K-tube winged All these are commonly cultd , their flrs should be examined *Paulownia* is an Oriental tree (China, Japan) cultd in S Eng , with opp cordate leaves and panicles of large purplish flrs , C-tube with 5 spreading lobes]

Digitalis and *Veronica* are closely allied, though apparently very different , some foreign Veronicas have long-tubed flrs

512. *Pedicularis* has 2 Brit species, both common, with pinnate leaves and red flrs in racemes, K with 2-5 irregular lobes, C 2-lipped, upper lip laterally compressed, lower 3-lobed ; A 4, under upper C-lip, anthers cohering by hairs *P sylvatica* (**Lousewort**), in damp fields, has a perennial rhizome; stems branched at base, rarely over 6 ins high , flrs (Apr -July) rosy , K-tube angular, 5-lobed, upper lobe entire, but the others leafy , upper C-lip 2-lobed *P palustris* (**Red Rattle**), annual, in bogs and marshes, with thick tap-root , stems 1-2 ft high, lower leaves opp , flrs (May-Sept) dull red , K-tube compressed, with 2 jagged lobes ; upper C-lip 3-lobed.

513. *Rhinanthus* (**Yellow Rattle**), in damp fields, annual, with square stem (6-18 ins) and simple narrow decussate serrate leaves , flrs (May-Aug) yellow, 12-30 mm. long, in a raceme , K inflated, with narrow mouth and 4 small teeth , capsule flat, with a few large winged seeds

514. *Melampyrum* has 4 Brit. species , *M. pratense* (**Cow-wheat**), the commonest, chiefly in woods (a shade-loving plant), annual ; stem 6-18 ins high, leaves decussate, narrow, entire (bracts toothed at base) , flrs (May-Sept) pale yellow, 15 mm long , K with 4 long teeth , C with long tube, lower lip with 3 short lobes and a "palate" nearly closing the mouth

515. *Bartsia odontites*, common on roadsides, in cornfields, etc., annual, with square stem and opp leaves ; flrs. (June-Sept) in a spike, all turned to one side , K 4-lobed, dull red , C red-purple, 1 cm long, mouth open

516 *Euphrasia* (**Eyebright**), annual, in fields, 1-10 ins high ; leaves opp , ovate, deeply toothed , flrs (May-Sept) as in *Bartsia*, but C white with purple veins and yellow lower lip, upper lip more spreading, tube shorter (5 mm)

517. Flower Mechanisms in Scrophulariaceae.—The flowers of most Scrophulariaceae are adapted for pollination by bees, though the short-tubed open flowers of *Veronica* and *Verbascum* are visited chiefly by flies In most cases the entering bee rubs the anthers and style with its upper side, and the flower is protected against rain by the hood-like upper corolla-lip In Toadflax and Snapdragon, however, the flowers stand erect, instead of being horizontal or pendulous, and the corolla-mouth is closed by the bulge or "palate" of the lower lip, so that it can only be opened by a heavy and strong insect, these flowers are visited by humble-bees, which often bite holes at the bulging base of the corolla-tube in Snapdragon In the Musk or Monkey-flower (*Mimulus*), notice the curious stigma, with two flat lobes what happens if the stigma is touched on the inner surface, and how will this help as regards pollination?

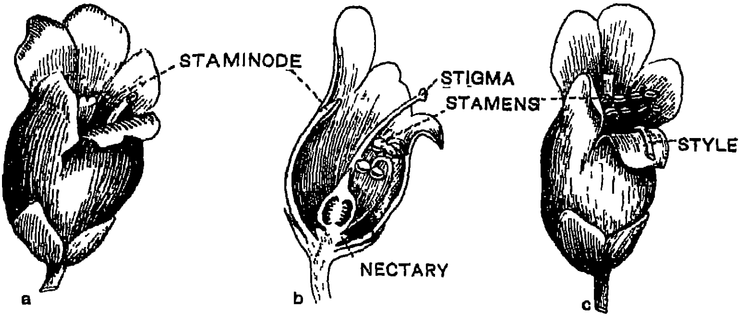
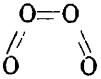


Fig 139.—Figwort (*Scrophularia*).

a, Flower when first opened, b, Longitudinal section of same, c, Flower day or two later In c the style and stigma are now withering, while the anthers are exposed and about to open

Figwort (*Scrophularia*), which is largely visited by wasps, is *protogynous* In the newly opened flower (Fig. 139) the style lies in the mouth of the corolla above the lower lip, but the anthers are still closed and hidden in the corolla-tube, the filaments being curved, next day, or a little later, the style withers and falls on the front of the corolla, the visiting insect rubs the stigma and anthers with its underside in this case The female stage is now over, and, unless cross-pollination has occurred, no seeds are formed Then the filaments unbend, bringing the anthers up to the position formerly occupied by the stigma, and a bee probing for the honey at the base of the corolla-tube is dusted with pollen, which it may then carry to the stigma of a younger flower

In *Rhinanthus*, *Pedicularis*, *Barstia*, *Melampyrum*, and *Euphrasia* we get a "loose-pollen mechanism" The stamens lie under the upper corolla-lip, and the four anthers are close together and usually connected by interlocking hairs in this fashion



so as to form a "pollen-box" The pollen is dry and powdery (like that of wind-pollinated flowers), and when a bee enters the flower it rubs against the lower side of the "pollen-box" and receives a shower of pollen on its head

QUESTIONS ON CHAPTER XXII.

1 Describe the structure of the Foxglove flower, with sketches, and point out its adaptation for pollination

2 Mention three British species of the genus *Veronica* (Speedwell) and give the characters by which you would know them one from another, including the months when each is in fullest flower Have you noticed any difference in the places where they usually grow?

3 Describe the flower of Mullein (*Verbascum*), pointing out how it resembles, and differs from, that of Foxglove.

4 For what reasons are Foxglove, Snapdragon, Toadflax, Figwort, Mullein, and Speedwell all placed in the same family? How do their flowers differ in structure?

5 How are all Scrophulariaceae distinguished from all Labiates? Which plants of both families might at first sight be confused, and how could you tell, from the flower, which family a plant with a two-lipped gamopetalous corolla and four stamens belonged to?

6 Mention Scrophulariaceae which are pollinated by (*a*) flies, (*b*) short-tongued bees, (*c*) humble-bees, (*d*) wasps

7 Describe the life-history of a single Figwort flower, from the time when its corolla opens

8 In what habitats would you look for Mullein, Ivy-leaved Toadflax, Brooklime, Cow-wheat, Lousewort, Bartsia, Yellow Rattle?

CHAPTER XXIII.

THE COMPOSITE FAMILY.

518. Dandelion (*Taraxacum dens-leonis*) is one of the commonest and most familiar of plants It is apt to be confused with Hawkweeds and other allied plants of the same family, but is distinguished by the lobing of its leaves, and by its solitary head of flowers being carried on a soft hollow stalk which arises from the centre of the leaf-rosette

Examine and compare plants growing in different situations, *e g* in exposed and in sheltered places, among short grass on a lawn, among longer grass in meadows, neglected lawns, or garden borders, in hard or gravelly soil and in soft damp soil Note that the leaves have a strong tendency to spread out in a rosette and press themselves to the soil (what happens if you carefully dig up a plant growing at the bottom of a wall and put it into level soil?), but that among long grass the leaves grow up in a nearly vertical position

Note the peculiar form of the leaves, which vary in the extent of the lobing and the shape of the lobes Why is the possession of lobed leaves an advantage to a short-stemmed rosette-forming plant? Note how the lobes of the different leaves fit together with very little overlapping Note also how rain-water falling on the leaves runs down the midrib to the tap-root, in which is stored the food that enables the plant to live from year to year The Dandelion is really an evergreen plant, since it is never without leaves.

In a dug-up plant note the long tap-root, which is usually blackish outside and white inside, cut across the root of a plant and note that soon a healing-tissue ("callus") forms over the cut surface, from which arise new shoots. It is not easy to tell, by inspection, where root ends and stem begins, the stem remains very short, covered by the leaf-bases, and each year it produces a bud for the shoot's further growth, while the root contracts (as in so many other "ground-hugging" plants, *e g* plants with runners, rosette-forming short stems, underground stems, bulbs, corms, or thick food-storing tap-roots) and draws the stem down so that it never comes above the soil What do you suppose is the use of the bitter juice contained in the Dandelion tap-root along with the reserve-food ?

The flowers, which appear in early summer but may be found (in south England and in sheltered places elsewhere) all the year round, are in solitary heads, each head on a long or short stalk The stalk is smooth and hollow, when cut it gives milky bitter juice (also found in other parts of the plant) which turns brown on exposure to the air Note the numerous (100 to 300) small flowers crowded on the flat expanded circular top of the flowering stem, each flower being inserted in a small pit Where are the youngest flowers—at the centre or at the outside of the disc ? By comparing heads of different ages you will find that the flowers open successively from outside to centre, so that the head resembles an umbel (*e g* Cowslip, Ivy) in which the flowers have no stalks (or very short ones) and are seated on the disc-like end of the flowering axis Note the double circle (*involucre*) of narrow green leaves (*bracts*) around the head

How do the outer bracts differ from the inner ones in form, position, and function ? Does either series appear to perform any function *besides* that of protecting the very young flower-head before any of the flowers open or the flowering axis grows up ? Why does the inner series remain erect, though the outer bracts bend downwards ?

In an open flower (Fig 140) note the narrow strap-like outgrowth from the outer side of the mouth of the corolla-tube How many teeth are there at the top of the strap ? Now examine the flower carefully with your lens Note the slender style, divided at the top into two curled branches (stigmatic arms), each about 2 mm ($\frac{1}{12}$ inch) long, with short hairs (in about 12 rows) on the inner (stigmatic) surface, note the long hairs on the style a little below the point of branching. Slit down the corolla-tube and trace the style down to the bottom of the tube; on its way down, the style passes through a tube about $\frac{1}{8}$ inch long; catch hold of the top of the style and pull it out of this narrow tube. What *is* this tube around the style? Can you see five slender threads joining the lower edge of this tube to the inner surface of the corolla-tube? If so, you should be able to see that the tube consists of the five anthers joined together by their sides; their outlines can, however, be seen on careful inspection.

What is the swelling below the base of the corolla-tube? Note the hairs which form a circle just above this swelling. Can you see a slender neck-like part between the swelling (ovary) and the ring of hairs (*pappus*, representing the calyx)? Can you see the small ring-like cushion (nectary) at the bottom of the corolla-tube, around the base of the style? If you cannot make out all these points in the structure of the flower at the first try, examine more flowers until you succeed in seeing all the parts. The honey rises in the narrow corolla-tube, so that even short-tongued insects can reach it. The heads are visited by an unusually large variety of insects, including hive-bees, humble-bees, flies, beetles, and butterflies.

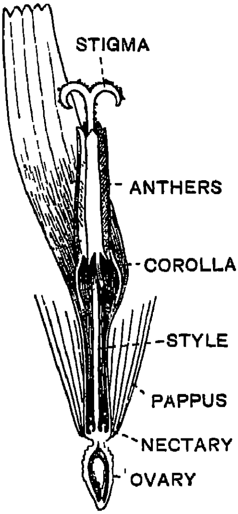


Fig 140.—Flower of Dandelion, lower part (corolla tube and ovary) cut open.

The Dandelion is a very suitable plant on which to make daily observations with a view to learning the complete life-story of the flower-head and of the individual flowers. By watching the same head at frequent intervals day by day, and by examining flowers of different ages, you can make out a good deal of the story for yourself. Is the head always expanded? Under what conditions does it close? Note how the straps of the outer flowers close over the inner flowers, and how the closing is completed by the inner circle of bracts Does it close at night only? For how many hours does it remain open each day in fine weather? Do *all* the flowers in a head open on the first day that the head itself is expanded? How often must the head open in order that all the flowers in it may have a chance of being pollinated by insects?

In watching Dandelion-heads in a garden I have noticed that, as an average, the heads are only open for about eight hours on fine days and that a head rarely opens more than thrice In fine weather nearly all the flowers in a head are open by the end of the third day, and on the fourth or fifth day the head is closed and the corollas are beginning to wither, while on cold and wet days the heads remain closed. How do these observations agree with yours?

Open up flowers of different ages, and note that at first the style is low down in the tube formed by the united anthers, the two stigmatic arms being in close contact by their inner (stigmatic) surfaces, the pollen is shed inside the tube, and is swept out of the top by the hairs on the style as the latter grows up During this "male" stage, insects visiting the head remove the pollen-mass from the top of the anther-tube as it is pushed up by the piston-like style, and since the stigmatic surfaces are not exposed, only cross-pollination is possible Then the style emerges and its two lobes diverge, exposing the stigmas, if cross-pollination does not occur during this second or "female" stage, the arms curve back until the stigmas touch the pollen still adhering to the style, thus bringing about self-pollination.

After the corollas have withered and the head has closed up for the ripening of the fruits, the head-stalk usually bends down towards the ground, and an interesting series of changes takes place What changes do you observe in (1) the length of the head-stalk, (2) the shape of the expanded top of the stalk (which is at first *flat*), (3) the size of the ovary, (4) the length of the slender stalk (at first *very* short) just above the ovary, (5) the ring of hairs at the base of the (now withered) corolla-tube? What becomes of the upper parts of the flower (corolla, stamens, style)? When the fruits are ripe, the stalk becomes erect again Does the head still open on fine days, or does it remain closed and for how many days? How is the change in form of the stalk-top connected with the change in form of the whole head? The "disc" is now becoming rounded (convex) instead of flat, while the fruiting head becomes a globular mass about two inches in diameter, the flat fruits require, therefore, to be spaced out on the "disc"

Do *all* the flowers in a head grow into fruits? Do you notice any difference in this respect between plants growing in sunny places and plants growing in shaded places? Why do the latter usually produce a smaller proportion of fruits than the former? Why are most of the unfertilised flowers usually found at the *outside* of the head? Probably the last three questions can be answered after considering the facts that efficient insect-visits are far more frequent (1) in sunny places and (2) in the more fully expanded and therefore more conspicuous heads, *i e* after the first day on which the heads are open.

These observations raise the question, is self-pollination an effective substitute for cross-pollination? I have tried experiments, designed to prevent insect-visits, with rather variable results, but on the whole the output of normal fruits has been much smaller than in neighbouring heads left untouched Tie small bags of muslin or, better, paper over young unopened heads, and see how many fully developed fruits are produced In watching Dandelion-heads and noting all that happened day by day I have found that the average time from the first opening of the flowering head to the final opening of the fruiting head (with fruits ready for dispersal) is about eighteen days, it is lengthened a little by rainy days, shortened when the weather is fine However, in this, as in all other readily verified matters, make your own observations instead of merely accepting those of other people

Note the structure of the ripe fruit (akene), opening up the fruit-wall to see the single seed Note how the parachute-like pappus (ring of hairs) closes up on wet days (why?) and expands on dry days (why?) By what agency is the seed dispersed? Try the effect of picking off the parachute from the fruit; note the times taken for (1) a complete fruit with expanded pappus, (2) the same fruit deprived of the pappus, to fall from the same height Try the comparison under different conditions, *e g* indoors and outdoors, on a still day and on a windy day Note the small stiff hairs (straight or hooked ?) on the akene itself How do these hairs help the akene to become attached to the soil after the parachute comes down ? What are the advantages of having the pappus carried up on a long stalk ? When is this stalk above the ovary developed ? Is there any trace of it in the *flower* ?

519. Daisy (*Bellis perennis*) —This familiar plant flowers from spring to autumn, even in winter a few days of sunshine will often cause the flower-buds to open. It is practically evergreen as well as perennial, producing leaves throughout the year In general habit it resembles the Dandelion, but the stem is longer and it sends out runners all round, giving rise to numerous new plants, apart from seeds, therefore, the Daisy has a very efficient method of spreading and multiplying

Carefully examine patches of Daisies at frequent intervals during the year, making notes (with sketches) of your observations At what time of year are the "runners" given off by the parent plant most copiously ? How many young plants may be formed in this way ? How long are the runners ?

Note the arrangement of the leaves in a rosette Sketch a plant from above, showing the shapes of all the leaves. Where is each leaf broadest ? What are the advantages of the peculiar shape of a Daisy leaf ? Which leaves (upper or lower) have the longest basal parts and the largest blades, and why ? Why is it a good plan for a rosette-forming plant to have its leaves broadest towards their free ends ?

Examine the flower-heads (Fig 141) and the individual flowers very carefully, on the lines indicated in the preceding article on the Dandelion How long are the flowering-axes ? How broad are the heads ? Note the shape of the expanded top of the head (slice it down longitudinally) and the structure of the involucre (number of bracts ? in how many circles ? shape and colour of bracts ?)

You will notice that the outer flowers, forming a single series, resemble those of the Dandelion in having a strap-like outgrowth from the mouth of the corolla, while all the inner flowers have a tubular corolla , the strap-like (*ligulate*) flowers are often called the ray-flowers, the small tubular ones the disc-flowers Compare a ray-flower of Daisy with a Dandelion flower note the shape of the strap, the narrow but short stigmatic arms, the absence of stamens In a disc-flower note the regular tubular corolla, with five (sometimes only four) equal lobes round its edge, the thick short stigmatic arms, the presence of stamens The ray-flowers thus differ from the disc-flowers in having no stamens, as well as in the shape of the corolla In what respect do *all* the flowers differ from those of Dandelion ?

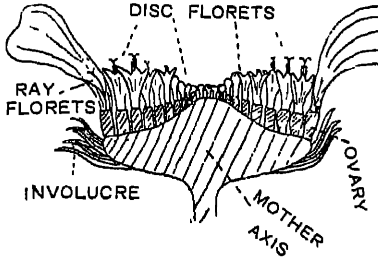


Fig 141 —Vertical Section of Capitulum

Note the closing of the head at night and in bad weather On a bright day the straps of the ray-flowers spread out horizontally, at night they move inwards and meet at the tops so as to cover and protect the young central flowers

Is it possible to make the head close in the daytime ? Cover a plant with a flower-pot or box, excluding all light by sprinkling soil round the edges where the pot or box rests on the ground Keep a Daisy in darkness for two or three days, then bring it to the light, or remove the pot or box covering it, note that the head does not open completely, but remains half closed, as is also the case on dull days Regular *alternation* of light and darkness is essential for the regular opening and closing of the heads

How are the opening and closing movements affected by changes in temperature ? Pick a head which has closed for the night, set it in a bottle of water, and bring into a warm room : a temperature of 15° C. or even more will fail to cause opening A Daisy head when closed in the evening does not readily open with even a considerable rise of temperature, when open in the morning it does not close unless the temperature is greatly lowered. If a closed head is warmed in the morning it readily opens, if an open head is cooled in the evening it readily closes

Note the elongation of the convex top of the flowering-axis after the flowers have been fertilised, and the flat akenes without a pappus. The compressed akenes are doubtless carried by the wind, though very poorly adapted for wind-dispersal as compared with Dandelion fruits. However, in comparing the equipment of plants for the struggle for existence, one must not fix on any single biological advantage, but take into consideration the whole equipment The akenes of Daisy cannot be so often carried to a distance as those of Dandelion, but once a Daisy plant establishes itself in a suitable place it may, by its runners, give rise to hundreds of plants in a few years

520. Coltsfoot (*Tussilago farfara*) is a well-known plant whose flowering shoots appear early in spring (sometimes as early as December), long before the large leaves. The plants grow chiefly in damp heavy soils, in waste places or road-sides, in clayey fields—usually in well-exposed situations.

Note the yellow flower-heads (1 to 1½ ins diameter), each carried on a stem (4 ins to 1 ft high) which arises direct from the ground and at first droops but later becomes straight The flowering-stem bears numerous scales which are, like the stem itself, covered with woolly hairs. At the top of the stem, just below the head, there are several short scales, then a series of long narrow bracts surrounding the flowers Are the flowers all alike, with tubular or strap-shaped corollas? How many ray-flowers are there? How do they (1) resemble, (2) differ from, those of the Daisy and Dandelion? Is there any pappus? How many disc-flowers are there in the head? Does the style bear diverging stigmatic arms, or not? By careful observation try to make out the life-history of the flower-head.

The central (disc) flowers appear to resemble those of the Daisy, but close inspection shows that they are really *male* flowers, for the style acts merely as a piston to push the pollen out of the anther-tube; the style does not divide into two stigmatic arms. The outer (ray) flowers are *female* flowers, as in Daisy, both kinds of flower have a pappus, but it remains small in the male flowers, though it enlarges to form a parachute on the fertilised ovary of the female flower Only the male flowers produce honey, insects visiting a newly opened head must (if cross-pollination occurs) bring pollen from an *older* flower (why?) When the head closes in the evening the pollen pushed out of the anther-tubes of the male (disc) flowers may be transferred to the straps of the female (ray) flowers, and when the head opens again the pollen may slide down the straps to the stigmas situated at the base, bringing about pollination.

Examine the leaves, which come up in a tuft, a few weeks after the flower-heads The leaves are upright and rolled up at first, but when the blade begins to unfold it turns over so as to be horizontal, and then rapidly spreads out and becomes from three inches to nearly a foot broad The leaf is covered, especially on the lower side of the heart-shaped angular blade, with a cotton-like mass of hairs (formerly soaked in saltpetre and used as tinder), the stalk is long and stout, and the fully grown leaf spreads out like an umbrella and stops the growth of other smaller plants below it.

Dig up a plant in early summer and note that each flowering shoot comes off independently from the stem, which bears the scars of the leaves of former years In plants dug up in autumn note the young leaves for next year, also the egg-shaped buds of the flowering shoots, in which the young flowers can be plainly seen on making a longitudinal section Note also the long white tough runners which arise from the stem and which enable the plant to spread over a large area The Coltsfoot is a rampant and troublesome weed when once it gets a footing in fields, owing to its rapid spread by means of the runners and to its very effective method of choking off competing plants by its large leaves

521. The Composite Family (Compositae) is the largest among flowering plants, and one of the most successful and widely distributed There are about 800 genera (40 in Britain) and 11,000 species (115 in Britain), *i e* over 10 per cent of the total number of species of Flowering Plants[1] There are nearly 1300 species of one genus (*Senecio*) alone

It is easy to see why this family is such an aggressive and successful one What are the advantages of having (1) numerous small flowers grouped together in a compact flat-topped head, (2) the outer flowers often more conspicuous than the inner ones, (3) honey in most cases accessible to even short-tongued insects, (4) in most cases small light fruits provided with a pappus?

Examine all the Composites you meet with and find out all you can about the arrangement and structure of the heads and of the individual flowers How do the heads and flowers of Cornflower and Knapweed ("Hard-heads") differ from those of our three types? What other Composites resemble (1) the Dandelion in having all the flowers ligulate, (2) the Daisy in having the outer flowers ligulate and the inner ones tubular, (3) the Cornflower ("Bluebottle") and Knapweed in having all the flowers tubular? How do the outer flowers of the Cornflower-head differ from the inner ones? What common Composites have small heads densely massed together to form a flat-topped corymb of heads, and what are the advantages of this arrangement? In each case study the biology of the inflorescence and of the individual flower, in the way we have studied the Dandelion and Daisy.

In studying garden Composites note the small leaves (bracts) on the top of the head, among the flowers, in Sunflower, Dahlia, and Zinnia, one bract on the outer side of each flower Compare "single" and "double" Dahlias, Asters, etc how does the flower-head become "double"? Watch the various insects which visit the flowers of wild and garden Composites why is there such a variety of visitors to flower-heads like those of Michaelmas Daisy? Groundsel, which flowers nearly all the year round, is said to be chiefly self-pollinated test this statement by experiment *Artemisia* (Wormwood, Mugwort) is said to be wind-pollinated examine its flowers carefully and note the adaptations to wind-pollination.

522. Composites may be roughly divided into three sections, with (1) all the flrs in the head ligulate, (2) all the flrs. tubular, (3) the outer flrs ligulate and the inner ones tubular. The first section is a natural one, but there are transitional forms between (2) and (3), and in thus dividing up those

Composites which possess any tubular flrs. we shall be bringing together some plants which are not closely related, and separating some which are.

There are 11 Brit. genera besides *Taraxacum* (Dandelion), which have all the flrs. ligulate, all have milky juice (latex), and all the common Brit. species (exc. Chicory) have yellow flrs.

523. Chicory (*Cichorium intybus*), in cultd. fields, roadsides, etc. (not in Scotland or Ireland), is a roughly hairy perennial with long tap-root, stem 1-3 ft. high, leaves pinnately lobed, flr.-heads (July-Nov.), 2 or 3 in axils of upper leaves, sessile, 2-4 cms. across; involucre of about 5 short outer bracts and 8 longer inner ones, flrs. large, bright blue; pappus = a ring of small erect scales.

524. *Lapsana* has no pappus. *L. communis* (**Nipplewort**), very common in cultd. and waste soil, annual, slender, much branched; heads (July-Oct.) in a loose corymb; each head 5-8 mm. diam., with 8-10 narrow rigid bracts and a few small outer ones.

The other genera have a pappus of long hairs.

525. I. Pappus-hairs simple (not branched and feathery)	
A. Pappus-hairs brown; akene not beaked	*Hieracium.*
B. Pappus-hairs white	
1. Akene tapering at both ends	*Crepis*
2. Akene with flat top, no beak	*Sonchus*
3. Akene with a long or short beak	*Lactuca.*
II. Pappus hairs feathery.	
A. Inv.-bracts very long, all of same length	*Tragopogon.*
B. Outer bracts small, narrow.	
1. Receptacle with scales between flrs.	*Hypochoeris*
2. Receptacle naked, no scales	
a. Stem nearly leafless, heads few	*Leontodon*
b. Stem leafy, branched, heads many	*Picris*
C. Outer bracts large and heart-shaped	*Helminthia*

526. The forms of *Hieracium* (**Hawkweed**) are many, and at first it is not easy even to tell a Hawkweed from the allied genera; some botanists distinguish as many as 30 Hawkweed species, others only 4 or 5 (the other forms being regarded as varieties). This genus, like *Rubus*, is a good example of "species in the making." There are 5 common Brit. species. *H. pilosella* (**Mouse-ear H.**), the commonest and most easily distd., has a rosette of entire leaves 2-4 ins. long, gives off runners (cf. Daisy), and has solitary pale-yellow heads, 2 cms. across, April-Oct., on a leafless stalk 2-9 ins. long; *H. murorum* (**Wall H.**) has a rosette of large ovate leaves and a few small leaves on stem

(1-2 ft high), which branches and bears 2-6 heads in a loose corymb, June-Oct, 2-4 cms. across, *H sylvaticum* (**Wood H**), in more shaded places, is taller, with narrower leaves less crowded in a rosette, and 5-8 leaves on flowering shoot; *H. boreale* (**Shrubby H**) has a stiff, woody, leafy stem, 1-3 ft, ovate leaves with teeth pointing upwards, lower leaves stalked and withering before flowering (Aug-Nov), inv-bracts blackish, heads many in a corymb, *H umbellatum* (**Narrow-leaved H**), 1-3 ft, has very narrow sessile leaves on wiry stems (no radical leaves), inv-bracts with recurved tips

527. *Crepis virens* (**Smooth Hawk's-beard**), very common in cultd and waste ground, annual, resembles Nipplewort (*Lapsana*) in habit, but easily distd by akenes (how?), with much-branched stem and small (5-20 mm) heads (June-Oct), *C paludosa* (**Marsh H.**), less common, has larger leaves, lobed like Dandelion, and larger heads

528. *Sonchus* (**Sow-thistle**) has 3 common species, all with hollow stems and jagged stem-clasping leaves, *S. arvensis*, chiefly in cornfields, has a creeping rhizome, angular stem 2-4 ft high, and large (2 ins diam) heads, *S oleraceus* and *S asper* are annuals, in cultd and waste places, with smooth stems, smaller (⅔-1 in) heads (more pointed when young), flowering earlier (June), *S asper* is like *S oleraceus*, but has more prickly leaves

529 *Lactuca* (**Lettuce**) has 1 fairly common Brit species, *L muralis*, on walls and in rocky copses, with numerous small (1 cm diam) heads having about 5 bracts and 5 flrs; leaves lobed, with large ivy-like end-lobe Examine the cultd Lettuce, which has about 10 flrs in head

530. *Tragopogon* (**Goat's-beard**), 1-3 ft high, in meadows, has long narrow entire smooth stem-clasping leaves, large (1-2 ins diam) heads (June-Aug), with about 8 long bracts, head closes at noon and in wet weather, fruit-head very large, akenes with long beak *T porrifolius* (**Salsify**), with purple flrs and very long inv-bracts, occurs as a garden escape

531. *Hypochoeris radicata* (**Cat's-ear**), very common in meadows, sandy places, etc., with lobed bristly leaves in a rosette, long tap-root, erect forked stem (1-2 ft) with a few very small leaves, heads (June-Sept), 20 cms diam, with numerous small overlapping bracts, akene with long beak

532 **Hawkbits** (*Leontodon*) have a rosette of leaves, a few very small leaves, or none, on flowering stems, and either a few heads (*L. autumnalis*) or only 1; the akene has no beak. *L autumnalis*, nearly hairless, leaves lanceolate with narrow blunt lobes, heads (Aug-Oct), 1 in across, *L. hispidus*, with stiff hairs, head 1¼ ins. across, on stalk 6-18 ins long, inv-bracts hairy, *L hirtus*, smaller, with hairy stalked leaves and numerous solitary flowering stems, heads ½-¾ in. across, inv-bracts not hairy

533. *Picris* has sessile narrow rough toothed leaves 4-12 ins. long up the stem (2-3 ft.), and bears prickly hairs, mostly hooked; heads (July-Dec.), 1 in. across, numerous, in a corymb. *Helminthia* (**Ox-tongue**) has tall (2-3 ft.) branched stems with broad cordate sessile leaves, covered with prickles on raised white spots, heads (June-Oct.) crowded.

534. The following Brit. genera have all the flrs. in the head always tubular, see also *Tanacetum* and *Senecio* in next section.

I. Leaves opposite.	
A. Heads large, flrs. yellow, rec. with scales	*Bidens*
B. Heads small, flrs. pink, no scales on rec.	*Eupatorium*
II. Leaves alternate.	
A. Woolly plants, heads small, flrs. yellow, white, or brown	
1. No pappus, no scales on rec.	*Artemisia*
2. Pappus silky	
a. Outer flrs. ♀, inner ☿ or ♂ or barren	
i. Rec. flat, without scales .	*Gnaphalium*
ii. Rec. conical, with a few scales	*Filago*
b. ♂ and ♀ flrs. in separate heads	*Antennaria*
B. Plants not woolly, heads large, flrs. red, purple, or blue	
1. Outer bracts with long hooked tips .	*Arctium*
2. Outer bracts spiny; leaves spiny .	*Carlina*
3. All the bracts gen. spiny, leaves gen. spiny	
a. Rec. with bristles between flrs.	*Carduus*
b. Rec. with a short collar at base of each flr.	*Onopordon*
4. No spines on leaves or bracts	
a. Bracts with a fringed border	*Centaurea*
b. Bracts not bordered .	*Serratula*
III. Leaves very large, long-stalked, coming after flrs.	*Petasites.*

535. *Bidens cernua* (**Bur Marigold**), in wet places, has simple toothed leaves 2-3 ins. long, stem short, 1-2 ft.; heads 2-4 cms. diam., single in leaf-axils, outer inv.-bracts spreading, inner erect; ligulate neuter ray-flrs. sometimes present; pappus = 4 barbed bristles; rec. with a large scale to each flr., *B. tripartitus*, in marshes, has 3-lobed leaves.

536. *Eupatorium* (**Hemp Agrimony**), also in wet places, but much commoner in Brit., is easily distd. by its tall stems (2-5 ft.), woody below and little branched, opp. leaves with 8 (or 5) leaflets (2-4 ins. long), small pink heads (July-Oct.) in dense corymbs, head with about 10 short bracts and 5 or 6 flrs., styles very long, pappus of simple hairs.

537. *Artemisia* has wind-pollinated flrs (Art 558) and much-divided leaves, flr.-heads small. *A vulgaris* (**Mugwort**) has leaves woolly below and about 20 flrs in head, in *A absinthium* (**Wormwood** heads larger) and *A. maritima* (**Sea Wormwood**, heads very small the leaves and stem are covered with woolly hairs.

538. *Gnaphalium*, *Filago*, and *Antennaria* include the **Cudweeds** very woolly plants with narrow entire leaves, *G. sylvaticum*, in woods has unbranched stem with pale yellow heads (5 mm diam) in axillar clusters, with brown shiny inv.-scales, *G uliginosum*, very common i wet places, has branched stems and terminal clusters of small head surrounded by long leaves, *F germanica*, in stony places, has ver small leaves and stiff forked stems with clusters of about 20 flr -head in the forks, inv -bracts brown and longer than flrs, *F minima*, no so common, has smaller leaves and only 2-6 heads in each cluster *A dioica*, on hills and heaths, has creeping stems with obovate leave and erect stems bearing small narrow leaves and a terminal cluster o 2-8 small heads (♂ heads 5 mm. diam, ♀ heads 10 mm.)

539 **Burdock** (*Arctium*), very common on roadsides, etc., 3-5 ft has very large cordate lower leaves, globular heads (June-Sept) bracts with hooked tips, becoming woody later, flrs purple, style white; pappus-hairs short

540 *Carlina* (**Carline Thistle**), biennial, 6-18 ins, has leaves wit spiny teeth, heads (June-Oct) 2-4 cms across, 3 or 4 in a corymb outer inv -bracts with prickly teeth, inner ones narrow yellow pointe and spreading out (often mistaken for ray-flrs), rec with bristle between flrs, flrs purple, pappus-hairs feathery

541. *Carduus* includes the true Thistles, of which the three com monest species, with pappus-hairs feathery, are *C arvensis* (**Creeping Thistle**, with burrowing rhizome which makes it a very troublesom weed; leaves narrow, much lobed, very prickly, heads 1-2 cms across, in corymbs, ♂ and ♀ flrs in separate heads on differen shoots), *C. lanceolatus* (**Spear Plume Thistle**, stem with spin wings; heads 2-3 ins across, solitary, inv -bracts with spreading spin tips), and *C palustris* (**Marsh Plume Thistle**, 4-8 ft high, ston winged, heads numerous, egg-shaped, 1 cm across, flrs rose-purple) Other species with feathery pappus-hairs are *C acaulis* (**Stemles Thistle**, in stony places, esp on chalk-downs, with a few large sessil heads on a very short stem in centre of leaf-rosette), *C heterophyllu* (**Melancholy Thistle**, in mountain pastures, with creeping rhizome tall stems 2-4 ft, and lanceolate leaves with small teeth, not prickl like other Thistles, head large and solitary), *C pratensis* (**Meadow Thistle**, also spineless but not common, 1-2 ft high, with down hairs, in wet meadows, heads gen solitary), and *C eriophorus* (**Woolly headed Thistle**, the stoutest species in Brit, 3-5 ft high, leave 1-2 ft, cottony below; heads globular, 2-3 ins. across, inv.-bract many, covered with a dense white web of hairs)

542. Three Thistles are distd from the foregoing by having the pappus-hairs simple *C crispus* (**Welted Thistle,** with continuous narrow wings on stem, 1-3 ft, leaves cottony below, heads small, 8-15 cms. diam, clustered, inv.-bracts narrow), *C nutans* (**Musk Thistle,** stem-wings interrupted, heads 2-5 cms diam, few, drooping; flrs crimson with purple anthers), and *C pycnocephalus* (**Slender-flowered Thistle,** chiefly near the sea, stem-wings continuous, heads pale pink, small, oblong, in clusters)

543 The **Cotton** or **Scotch Thistle** (*Onopordon acanthium*) differs from the true Thistles (*Carduus*) in having no bristles between the flrs on the receptacle, which shows pits each surrounded by a jagged collar, it is a stout biennial, up to 6 ft high, with broad prickly leaves, winged stem, large erect globular (3-8 cms diam) heads, inv swollen below and narrow above, bracts spiny, recurved, with cobweb of hairs

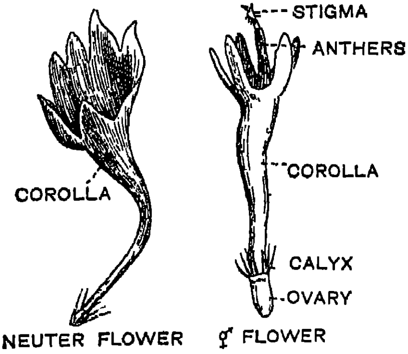


Fig 142 —Corn Cockle (Centaurea).

I, Outer neuter flower (8), II, Tubular hermaphrodite flower (× 6)

544. The commonest species of *Centaurea* is *C nigra* (**Hardheads,** Knapweed), with lanceolate entire or slightly-lobed leaves (1-3 ins long), heads (June-Sept) 2-4 cms across, inv-bracts overlapping, each with a broad black fringed margin, head either with or without larger neuter outer flrs, pappus of very short bristles *C scabiosa* (**Greater Knapweed**) is larger, more branched, with deeply lobed leaves 4-10 ins. long), head larger, always with a "ray" of neuter flrs, inv-bracts broader, with a narrow black fringe *C cyanus* (Fig 142), (**Bluebottle**), in cornfields, has very large blue outer neuter flrs and is often cultd.

545 **Saw-wort** (*Serratula*), chiefly in dry woods, has a slender stem (2-3 ft), pinnately-lobed leaves (5-9 ins), heads (Aug) ovoid, unisexual, ♂ or ♀ gen on separate plants, flrs red-purple, ♂ with blue anthers and joined style-arms (acting as pollen-piston), ♀ with white abortive anthers and spreading style-arms, rec with bristles between flrs , pappus-hairs longer than akene, rigid

546. *Petasites vulgaris* (**Butterbur**) is closely allied to Coltsfoot, having large (up to a yard across) cordate leaves on long stalks, appearing after the flowering shoots, it grows in moist places, esp by streams, and has a stout fleshy creeping rhizome, the flowering-shoots (Mar - May), up to 2 ft high, bear many white or purplish heads, ♀ plant has a compact panicle of heads, each 12 mm across, containing about 150 ♀ flrs with very narrow C and long style, ♂ plant has smaller (8 mm) heads (about 30 flrs) in a looser panicle, ♂ flr with bell-shaped C and club-like style (ovary pres., but no ovule), sometimes the ♀ head has a few central ♂ flrs , and *vice versa*

547. The British Composites in which the outer flrs of the head have ligulate corollas and inner ones have tubular corollas are fairly easy to identify In some genera certain species, *e g* Groundsel in genus *Senecio*, have no outer ligulate flrs , but these cases present no difficulty when the allied species are known

I Akene without a pappus	
A Ray-florets with very small ligule	*Tanacetum*
B Ray-florets with well-marked ligule	
1 Receptacle with scales or bristles between flrs	
a Ligule of ray-flrs short and broad	*Achillea*
b Ligule of ray-flrs oblong	*Anthemis*
2 Receptacle naked	
a Receptacle flat or convex	*Chrysanthemum*
b Receptacle conical, becoming elongated	*Matricaria*
II Akene with a pappus	
A. Ray-flrs purple	*Aster*
B Ray-flrs yellow	
1 Inv -bracts long and equal, often with a few very small scales at base	*Senecio*
2 Inv -bracts numerous and overlapping	
a Ray-flrs over 20 , anthers tailed	*Inula*
b Ray-flrs about 10 , anthers not tailed	*Solidago.*

548 *Tanacetum vulgare* (**Tansy**), common but not native in Brit , is a rather shrubby plant, 2-3 ft , with strong scent and bitter taste, comp pinnate leaves with toothed leaflets, numerous button-like yellow heads (Aug -Oct), 8 mm across, in a dense corymb, outer flrs ♀ with a very short 3- or 4-lobed ligule on C, inner flrs ⚥ with tubular 4- or 5-toothed C, pappus repd by a narrow membrane on the 5 ribbed akene, *T* is allied to *Artemisia* (note differences between the 2 genera)

549 *Achillea* has 2 common Brit. species *A millefolium* (**Milfoil, Yarrow**) has much divided leaves and small white or pink heads (May-Sept) in a dense flat corymb with 5 or 6 ray flrs , *A ptarmica* (**Sneezewort**) has simple narrow serrate leaves, fewer and larger greenish-white heads (July-Sept) with about 12 ray-flrs

550 *Anthemis* has 2 common Brit species *A cotula* (**Stinking Mayweed**) has feathery twice pinnate leaves, white heads 1 in across rec convex and lengthening in fruit, ray-flrs neuter (without a style), *A arvensis* (**Corn Chamomile**) has woolly leaves, large heads, rec does not elongate and has scales longer than disc-flrs , ray-flrs ♀.

551. *Chrysanthemum* has 2 common Brit species *C leucanthemum* (**Ox-eye Daisy**) has toothed leaves (lower spoon-shaped, upper oblong sessile) and large white heads (2 ins across), disc-flrs yellow, *C segetum* (**Corn Marigold**) has oblong stem-clasping toothed leaves, heads 2 ins across, flrs all yellow

552. *Matricaria* has 2 Brit species *M inodora* (**Scentless Mayweed**) is very common, with leaf divided into many narrow lobes, heads 2 ins across, ray-flrs. white (sometimes very few) , *M chamomilla* (**Wild Chamomile**) is fairly common, scented like *true* Chamomile (*Anthemis nobilis*), but with smaller heads (1-2 cms across) and distd from it by having no scales on rec between flrs

553. *Aster tripolium* (**Michaelmas Daisy**), in salt marshes, has stout stem 2-3 ft. , entire fleshy leaves 3-5 ins long , heads (July-Sept) 2 cms across, in a corymb ; ray-flrs pale purple, sometimes few or absent

554 *Senecio* is the largest genus of Flowering Plants, having over 1,200 species (only 9 in Brit) ; the cultd **Cinerarias** are foreign species of *Senecio* The 5 commonest Brit species are *S vulgaris* (**Groundsel**), which has no ligulate ray-flrs in its small inconspicuous yellow heads (all year round, mostly self-pollinated) ; *S sylvestris*, leaves more deeply cut, heads (July-Sept) 6 mm long, 3 mm across, yellow, ray-flrs with short ligules rolled back , *S jacobaea* (**Ragwort**), leaves deeply lobed, heads (June-Sept) large (1 in across) yellow in corymb, ray-flrs with long spreading ligules , *S aquaticus* (**Marsh Ragwort**), has less cut leaves and a looser corymb , *S crucifolius* (**Hoary Ragwort**) is less common, leaves woolly below and simply pinnate-lobed, heads as in common Ragwort

555. *Inula dysenterica* (**Yellow Fleabane**), woolly, with oblong stem-clasping leaves, has bright yellow heads (July-Sept.), 1 in diam few on stem, ray-flrs with long narrow ligules, *I conyza* (**Ploughman's Spikenard**), not so common, has apparently only tubular flrs, the ray-flrs having minute ligules, stem 2-5 ft, leaves 3-5 ins, ovate downy below, heads (July-Sept) 15 mm across in corymb, *I crithmoides* (**Golden Samphire**), in salt marshes, has a stout unbranched stem, 6-18 ins, covered with narrow sessile fleshy leaves, heads 1 in across

556 *Solidago virgaurea* (**Goldenrod**), in moist woods, has lanceolate leaves and small (8 mm) bright-yellow heads (July-Sept) in a dense cluster, head with about 10 ray-flrs and 20 disc-flrs

557. Cultivated Garden Composites.—Many Composites are grown for their flowers, and several as vegetables They are mentioned here in roughly the same order as in the preceding notes on native British Composites

The Lettuces are luxuriant species and varieties of *Lactuca*; Chicory (root ground and used to mixed with coffee), Endive (used like Lettuce) is another species of *Cichorium*, Salsify (roots cooked and eaten) is like the Goat's-beard but has purple flrs, *Scorzonera* (used like Salsify) is allied to Dandelion, but has entire leaves and beakless akene with feathery pappus, *Catananche* (Cupid's Dart, almost the only Ligulate Composite cultd for its flrs) has papery bracts and a pappus of pointed scales

Allied to Mugwort are *Artemisia abrotanum* (Southernwood) and *A dracunculus* (Tarragon, leaves narrow and entire), both cultd for their aromatic leaves, *Gnaphalium* (*Antennaria*) *margaritaceum* (Pearly Cudweed), *Helichrysum* (French Immortelle), and *Helipterum* are the common "everlastings" or "Immortelles," heads with papery bracts, often sold dyed, *Leontopodium* (Edelweiss) *Ageratum*, allied to *Eupatorium*, has blue or white flrs, pappus = pointed scales

Centaurea cyanus and other species are much cultd as "Cornflower and "Giant Knapweed", *Cynara scolymus* (True or Globe Artichoke, rec and fleshy bracts of young flr-heads edible) and *C cardunculus* (Cardoon, soft inner leaves blanched and eaten like celery) are prickly plants akin to *Centaurea* and the Thistles, *Echinops* (Globe Thistle) has spiny leaves and numerous small single-flowered heads in a globular blue cluster

Most of the cultd Composites have heads of the Daisy type, with the ligulate ray-flrs gen ♀ or sterile They mostly have "double" varieties, with the normally tubular corollas of the disc-flrs. drawn out like straps or quills, but in some cases, esp. marigolds, the seedlings of the "double" varieties tend to revert to the normal or "single" type In most cases the normal forms are also cultd, and there is no fear of confusing the "double" forms with the true Ligulate Composites of the Dandelion type if the "double" varieties are carefully compared with the normal forms of the genus in each case Note that the "double" *heads* of these Composites are very different in nature from the "double" *flowers* of Rose, etc.

Helianthus and its allies are distd. by having scales on the rec. between the flrs., and opposite leaves; *H. annuus* and others (Sunflowers) are cultd. for their flrs. (examine a head, noting the large scale to each flr., the neuter ray-flrs. with untoothed ligule, the calyx of 2–5 scales—larger in the disc-flrs.), while *H. tuberosus* ("Jerusalem" Artichoke, Italian *girasole* = "turning to the sun") has tubers somewhat like those of Potato, but containing inulin (as in Dahlia root-tubers); *Heliopsis* (Orange Sunflower), akin to *Helianthus*, has long serrate leaves; *Rudbeckia* (Cone Flower) is distd. by having the rec. conical instead of flat; *Coreopsis* (Tickseed) has curious akenes, flat on one side, convex on the other, crowned by 2 horn-like appendages, head gen. with only 8 ray-flrs.; *Zinnia* is similar, with few ray-flrs. (in the "single" form, the "doubles" are much cultd.); *Dahlia* has a double inv. (with numerous outer bracts spreading or reflexed, and about 8 inner ones joined at base), rec. with large scales, no pappus; *Cosmos* (Fennel Dahlia) also has a double inv. (about 10 bracts in each series), akene with 2-4 bristles.

Tagetes (French, African, and Mexican Marigolds) is peculiar in having a cup-like inv. of (gen.) only 5 bracts joined nearly to top, 5 or more ♀ ray-flrs., each flr. with calyx of 5 small sepals (1 replaced by a bristle in case of disc flrs.); the flrs. are very suitable for dissection ("single" forms).

Calendula (True or Pot Marigold) has numerous ♀ ray-flrs. in 2 or 3 circles; disc-flrs. ♂, no pappus. In *Gaillardia* (Blanket Flower), akin to *Tagetes*, the rec. has bristles between the flrs., and pappus = 5 bristles. *Helenium* (Elecampane), allied to *Inula*, has inv.-bracts joined at base and a series of bracts within the ray-flrs. (ligule 3-lobed at tip), pappus = 5 bristles; several species of *Inula* are cultd.

Several kinds of *Senecio* (Ragwort) are grown (the endless vars. of Cinerarias belong to this genus); the allied genus *Doronicum* (Leopard's-bane) is distd. by its ray-flrs. having no pappus.

Allied to the Daisy (several "double" varieties of which are cultd.) are the following:—*Aster* (Michaelmas Daisy, tall late-flowering perennials, never double), with inv. of numerous overlapping bracts and flat akenes with hairy pappus.

Callistephus (China Aster, annuals, large heads, often double) has a double pappus (outer = short united bristles, inner = long hairs); *Chrysocoma* (Golden Aster) has small spherical heads, all the flrs. tubular and ☿, pappus simple; *Charieis* (Cape Aster) has a double inv. (outer bracts flat, inner keeled), rec. pitted (pits toothed at edges); *Brachycoma* (Swan-river Daisy), allied to *Bellis* (Daisy), dwarf annuals with deeply-cut leaves, rec. conical, pappus of short hairs; of *Solidago* (Goldenrod, "Golden Spiraea") many vars. are grown, distd. by the rod-like stems (gen. unbranched), serrate leaves, small heads (ray-flrs. gen. 5) in spikes or racemes, often all turned to one side, sometimes drooping; *Erigeron* ("Fleabane," "Orange Daisy"), small plants with numerous narrowly-ligulate ray-flrs.

Besides *Chrysanthemum* itself, with double vars (single kinds—Marguerites, Moon Daisy, Shasta Daisy, etc —resemble Ox-eye Daisy in structure), several closely-allied genera are grown *Pyrethrum* (flowering summer and autumn) has pappus repd by scaly collar, *Parthenium* (Feverfew) has gen 5 ray-fls, rec with scales, akene flat with pappus of 2 scales *Leptosyne* has outer inv of gen 5 broad spreading bracts, and inner of several erect bracts on the Marguerite-like fl-heads

558. Mechanisms in Compositae.—The general structure of the flower is remarkably uniform throughout this huge family As regards the number of flowers in a head, we get every transition from the single-flowered heads of Globe Thistle (*Echinops*, cultd), through the few-flowered ones of Hemp Agrimony, etc , to the huge heads of Sunflowers with hundreds of flowers

In all cases the head is surrounded by an envelope (involucre) of bracts, which may be in one or two circles, or spirally arranged and numerous, generally free but sometimes joined, and which in some cases perform "sleep"-movements or close up on being moistened The inv -bracts are usually green and therefore carry on assimilation, but they serve mainly to protect the young flowers and, later, the developing fruits, so that they perform for the Composite flower-head the same functions that in most other plants are performed by the calyx of the individual flower When spiny, the involucre protects the flowers against browsing animals, and when the spines are hooked (*e g* Burdock), it serves for animal dispersal of the "seeds" (akenes)

Since the ordinary functions of the calyx are transferred to the involucre, the sepals of the individual flowers are rendered unnecessary in this respect, and are often represented only by a few small scales (free, or joined to form a collar) or bristles, but in many cases it forms a pappus of long hairs which may be sessile or raised, after fertilisation of the flower, on a long stalk The pappus-hairs are either rigid or silky, and either simple (unbranched) or bearing minute knobs or secondary hairs (feathery pappus), they are usually hygroscopic, spreading out like a parachute in dry air and forming a most effective means of wind-dispersal, and at the same time helping to loosen the fruits and detach them from the receptacle In some cases, e g *Bidens* (Bur Marigold), the pappus consists of barbed bristles, serving for animal-dispersal. In Composites without a pappus the receptacle often contracts in drying, so as to loosen and even jerk out the fruits (Sunflower, etc.), or becomes conical (Daisy, *Rudbeckia*, etc.), so that the fruits may be more readily carried away by wind.

The common receptacle which carries the flowers—the enlarged end of the flowering axis—is generally flat or rather convex, and is either naked or bears bracts corresponding to the individual flowers. In some cases each bract is divided into numerous bristles (*e.g.* Knapweed, Thistles), or is represented by a fringed collar at the base of each flower (*e.g.* Cotton Thistle).

The corolla is either tubular (generally having a narrow lower part and an expanded upper part with five lobes) or zygomorphic (the tubular corolla is generally symmetrical, but sometimes not strictly so—*e.g.* in cornflower). Of the zygomorphic corolla there are several types. [In *Mutisia* (some species grown as climbers, tendril = prolongation of leaf-tip) and its allies (tropical plants) the flowers (or at least the outer ones) have a 2-lipped corolla, the longer lip 3-lobed, and the shorter lip 2-lobed.] In Dandelion and its allies (Hawkweeds, etc.) the mouth of the corolla is drawn out, on the outer side of the flower, into a strap with five teeth at the end; this is the true ligulate type. In most heads of the Daisy type the strap-like lower lip of the ray-flowers is either entire or divided into three lobes at the end. Other "falsely ligulate" types are seen in the numerous "double" varieties of Dahlia, etc.

The Composites are practically all insect-pollinated, and have a beautiful and effective mechanism of a comparatively simple type, already described for Dandelion (Art. 518). The grouping of the small flowers into heads—an arrangement not peculiar to Composites but found in many other families, *e.g.* Scabious, Sheep's-bit, Sea-Holly, Clovers—brings about a saving in corolla-material, besides enabling a single insect-visitor to pollinate several flowers in a short time and causing the flowers to form a conspicuous mass (this is heightened by the frequent arrangement of the heads, when small, in corymbs or racemes, or even—in Globe Thistle—compound heads, *i.e.* heads of heads).

The most striking arrangement is that in which the outer flowers, forming the ray, differ from the inner ones in having ligulate corollas, or larger tubular corollas (Cornflower) In such cases the outer flowers are generally female and the inner ones hermaphrodite, this is probably due simply to the extra material for the large corolla of ray-flowers being supplied at the expense of the stamens, and these flowers are in many species rarely fertilised—in some cases they are completely sterile, having no style or ovule (Cornflower)

Cross-pollination is made inevitable in a few cases, owing to the flowers being unisexual, the male flower having an empty ovary and a style which acts only as a pollen-piston In some such plants the head contains only male or female flowers, and the male and female heads are on separate plants, *e g* Saw-wort (*Serratula*), Creeping Thistle (*Carduus arvensis*), Butterbur (*Petasites*), in *Calendula* (Pot Marigold) the head has a few ligulate female flowers and numerous tubular male disc-flowers, Coltsfoot (*Tussilago*) has been fully described (Art 520) Even when all or most of the flowers are hermaphrodite, the flowers open successively towards the centre of the head, so that pollen will usually be brought by insects from another head, failing that, self-pollination nearly always occurs eventually owing to the curling-back of the stigmas

The mechanism of the essential parts is practically uniform in the whole family The union of the anthers to form a tube is apparently due to their edges secreting gum, which sticks them together, and not to "congenital growth" as in the cases of the gamopetalous corolla, monadelphous stamens, etc In most cases the corolla-tube is short enough to allow all except the shortest-tongued insects to reach the honey secreted by the ring-like nectary at base of style The depth of the tube varies considerably, but in most cases the lower part of the tube is so narrow that the honey rises in it and can be sipped by long-tongued flies and short-tongued bees, the longest-tubed forms (*Centaurea*, Thistles, etc) are chiefly visited by butterflies and the long-tongued bees, the shortest-tube forms (*e g* Milfoil, Daisy) by flies It is interesting to watch a Michaelmas Daisy (*Aster*) in a garden on a fine day, and to note the great variety of the insect-visitors—flies of all sorts, bees, wasps, butterflies

Most species of *Centaurea* have irritable stamens, sensitive to contact When an insect touches the stamens, the filaments contract and force a mass of pollen out from the top of the anther-tube. The mechanism is easily observed in the Cornflower With a camel-hair brush or a pointed match-stick remove the pollen projecting from the anther-tube of a newly-opened flower (in which the style has not yet grown out), and note the thread of pollen which emerges

Next carefully slit open the corollas of a few young flowers removed from the flower-head, set the flowers in a watch-glass or on a glass slide under a bell-jar for a few minutes (to let them recover), then touch the filaments and note their writhing contraction Each filament can be made to contract independently, pulling the anther-tube over to the corresponding side, as well as drawing it downwards, so that the pollen-mass present above the style is squeezed out and carried away on the insect's head

Artemisia (Mugwort, Wormwood) is peculiar in having flowers adapted to wind-pollination The pollen-grains are smooth (not spiny or ridged, as in other Composites), dry, and powdery, and the small dingy flower-heads are on long flowering stems carried well above the large leaves, the heads droop in Sea Wormwood The anther-tube projects a little beyond the tubular corolla, and has bristles on its upper edge which hold the pollen in a sort of basket, so that it may be gradually blown away Then the style emerges and the stigmas spread out, each stigma has a large fanlike fringed end, presenting a large surface to receive pollen

QUESTIONS ON CHAPTER XXIII.

1. Describe the vegetative organs (root, stem, leaves) of a Dandelion. Why is this plant a troublesome weed in lawns?

2 Describe the arrangement and shape of the leaves of a Dandelion. What differences in the leaves have you noticed in plants growing in diverse habitats, and how may these differences be explained?

3. Describe the structure of the flower-head of a Dandelion Why is it wrong to call the head a flower?

4 Describe the structure of a single Dandelion flower, and relate any observations and experiments you have made on its biology, stage by stage

5. Give a general account of the life history of a Dandelion flower-head as seen by watching the same plant day by day from the time it is first visible How often did the head open and close? For how long did it remain open during a single day? Did it open every day—if not, on what sort of day did it (*a*) open, (*b*) remain closed?

6 Describe, from your own work, the adaptations of the flowers of Dandelion for cross-pollination by insects Is there any provision for self-pollination? If so, explain the mechanism, with a series of sketches (from the actual plant)

7 Describe the way in which a Daisy spreads over a lawn Compare it in this respect with the Dandelion. How many young plants have you observed in course of formation by the parent plant? Why do you suppose the Daisy resorts to this method of spreading apart from seeds?

8 Compare the flower-heads and flowers of Daisy with those of Dandelion Which plant seems, from your own observations, to propagate itself most freely by *seed*?

9 In how far may a Daisy flower-head be compared with a flower?

10 In what sort of locality, and in what sort of soil, have you seen Coltsfoot growing? How does Coltsfoot spread (apart from seeds) and what makes it a tiresome weed in fields?

11. Describe carefully the appearances presented by a Coltsfoot plant month by month throughout the year that is, give a brief "diary" of its year's life, noting such points as the time when the flower-head is first formed, when it emerges from the soil, when it opens, how long it remains open, when it closes again, when it re-opens to let the fruits escape, when the leaves emerge, how they expand, etc

12 Describe fully the flower-head and flowers of Coltsfoot, and compare the pollination arrangements with those seen in Dandelion and Daisy.

13 Why are the Composites called "an aggressive and successful family"?

14 Write an account of the "division of labour" seen in the flower-heads of Daisy and Coltsfoot

CHAPTER XXIV.

THE IRIS AND LILY FAMILIES.

559. Monocotyledons and Dicotyledons.—As already stated (Art 415), the Flowering Plants are divided primarily into two groups—a lower group (**Gymnosperms**, Ch XXVI) and a higher group (**Angiosperms**) The latter is divided into two classes—a lower class (**Monocotyledons**) and a higher class (**Dicotyledons**), the former having an embryo with one cotyledon, the latter an embryo with two cotyledons Even this distinction is not absolute, and the other distinguishing marks are even more liable to exceptions if taken singly, but on the whole it is always easy to tell a Monocotyledon from a Dicotyledon

Monocotyledons generally have the stem-bundles scattered in cross-section, the individual bundles are "closed" (without a cambium-layer), the main leaf-bundles (veins) are parallel and connected by delicate cross-veins, and the flower-parts are in threes In Dicotyledons the stem-bundles are generally arranged in a single ring as seen in cross-section, the bundles are "open" (with cambium between bast and wood), the finer leaf-veins form an irregular network, and the flower-parts are in twos, fours, or fives Very few plants "break" more than two or three of these rules, and probably no plant breaks them all, in exceptional cases the plant's position is usually easy to define on its general affinities, instead of by applying more or less arbitrary laws

560. Crocus.—The life-history of Crocus should be carefully studied by continuous observation, according to the following detailed instructions

Note that a dry resting-corm is almost entirely covered by brown **scales,** thin and dry What can you see of the structure of the scales? Pull off a bit of this scaly covering which surface (outer or inner) is rough and dull, and which is smooth and shiny? In which direction can the scales be torn easily, and why? Do the strings or fibres, of which the scales are almost entirely made up, run parallel, or do they diverge and form a network, or do they show both of these arrangements? What do you think the strings are, or at any rate were at one time?

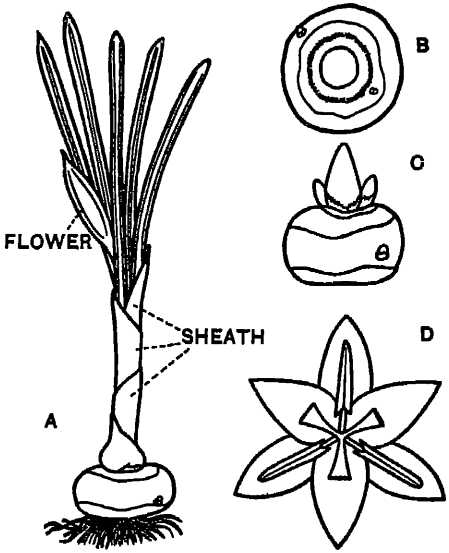


Fig 148 —Crocus. A, Entire Plant just before the Flower has opened, B, Corm from below, C, Side view of Corm, D, Flower as seen from above

Now look at the flat or concave lower end of the "bulb" (how can you tell which is the lower end?) and notice the roughly circular patch Unless you have examined Crocuses after they have been dug up when the growth of flowers and leaves had finished for the season, you cannot tell how this patch was formed. What can you see on the lower end of the "bulb," just outside of this patch? Sometimes one can plainly see numerous short slender white pointed projections in this part, arranged in a ring If you can see these, you should be able to guess what they are.

Now remove the scales carefully one by one, starting from the lowest Notice that each scale goes right round the "bulb," and that on removing it you can see a brown line where the scale was attached (Fig. 143). What name might be given to each of these lines? What name is given to the place where a seed breaks from its stalk, or a leaf from the stem? Would you call the hard white solid mass to which these scales are attached a **stem?** We know that a stem bears leaves and buds As you remove the scales, notice that they become more crowded at the top, so that the scars are closer together here What do you see projecting from this upper end? Can you find any similar projections lower down? In most cases you will find one between any two neighbouring scars What are these projecting bodies?

From these observations you should be able to infer that the "bulb" is a short thick stem bearing **buds.** It is distinguished from most bulbs (Onion, Tulip, etc) by having a thick stem and thin dry scales instead of a very small stem and thick fleshy scales, it is therefore called a "solid bulb" or **corm.**

Now pick off one of the large buds from the top of the corm, and very carefully dissect it, making a sketch of the entire bud and of each part you remove from it Notice first the **scales:** how many are there, how are they inserted (trace each one carefully to its base), how do they resemble the scales you picked off the corm itself, and how do they differ from these? Next notice the young yellowish or green **foliage-leaves,** each having a broad base inserted like a ring around the lower part of the bud; this part is not easy to make out clearly, so you may have to try several buds

What do you find in the centre of the bud? In most cases you will find one, two, or (in some Crocuses) more tapering, pear-shaped bodies covered by a papery sheath, and tapering to a point above and into a stalk below Each of these bodies resembles a bud what kind of bud can it be? Peel off the sheath what do you find inside? This, then, is a **flower-bud,** containing a young flower Notice the long tube ending above in six pointed oval lobes; the stamens (how many?), which are already very large as compared with the "petals"; the style, ending in three fan-like stigmas

Now examine some Crocus plants in flower and in earlier stages of growth, or plant some corms in moist sawdust or soil (just as you did with seeds of the Broad Bean and other plants), and watch their growth Notice the swelling and upward growth of the buds, the roots which spring from the base of the corm, arranged in a ring, the sheath, consisting of the enlarged bud-scales, which covers the young shoot until it has grown well above the surface of the soil, the bursting of the sheath and the appearance of the foliage-leaves, which are now bright green in colour, the escape of the flower from its sheath, which consists of two white membranous leaves (bracts).

Examine the flower carefully, noting and comparing what you see in flowers in different stages, or in the same flower day by day from the time of its emergence from its sheath Note the six coloured lobes, three outer and three inner, which form the most conspicuous portion of the flower, and which arise from a funnel-like structure, prolonged below into a long narrow tube The tube, funnel, and lobes together form the *perianth*, this term being used when there is no clear distinction into calyx and corolla But it would be simpler to call the three outer lobes "sepals," the three inner ones "petals," and the tubular part the "flower-tube"

Note the three stamens, each consisting of a long anther (showing the four pollen-sacs very distinctly) and a short filament the latter is inserted on the mouth of the flower-tube, opposite a "sepal," and the stamen is spear-shaped owing to the anther being produced into a sharp point on each side of its base (where the filament is attached). Note the three fan-like stigmas, with more or less toothed or frilled edges, continued below into the style; cut open the flower-tube and trace the slender style right down. Both the style and the flower-tube arise from the top of a swelling, the ovary, cut the ovary across and notice the numerous "young seeds" arranged in two longitudinal rows on the inner side of each of the three ovary-chambers. Below the ovary is the flower-stalk, the bracts spring from this stalk, just below the ovary.

Close observation of a flower day by day will show that the lobes spread out in the daytime and move inwards at night, thus causing the opening or closing of the flower. The flower opens when exposed to light, sufficient warmth, and dry air, whilst its closing may be caused by coldness or dampness of the air as well as by darkness. The movements of opening and closing can, by careful measurement, be shown to be caused by the outer sides of the perianth-lobes growing faster (closing movement) or more slowly (opening movement) than the inner sides. What are the advantages to the flower of this power of opening or closing? What other plants, growing wild or in gardens, have flowers which open on bright days and close on dull or wet days and at night? For how many days does a Crocus flower last?

It is easy to discover that the anthers open by two slits, shedding the pollen outwards, *i.e.* away from the centre of the flower, that this happens while the stigmas are in contact with each other, and that a day or two after the anthers have opened the three stigmas separate and spread out, one opposite each *inner* perianth-lobe. Do you see how this helps in promoting cross-pollination? The Crocus flowers are visited by bees, butterflies, and moths.

The Crocus contains honey in abundance, as can easily be seen by opening up the perianth-tube; the honey, produced by glands in the partitions between the three ovary-chambers, rises up the tube and can be sipped by bees entering the flower. The bee stands on the perianth-lobes and pushes its head into the funnel-like mouth of the tube, seeking for the honey, and in doing this it touches the stigmas (if these have spread out) and then the stamens. If, however, cross-pollination fails to occur, the stigmas may curl over and touch the anthers, bringing about self-pollination.

After the flowering period the perianth, stamens, stigmas, and style wither; if fertilisation has occurred the ovary grows larger and forms the fruit, which later on is carried upwards by the lengthening of the flower-stalk. The fruit (capsule) ripens about the end of June (in Spring Crocuses) and splits down the middle of each chamber, setting the seeds free.

Long after the flowers have withered the foliage-leaves persist, carrying on photosynthesis and storing up food.

Where, and in what form, is this food stored? Examine a

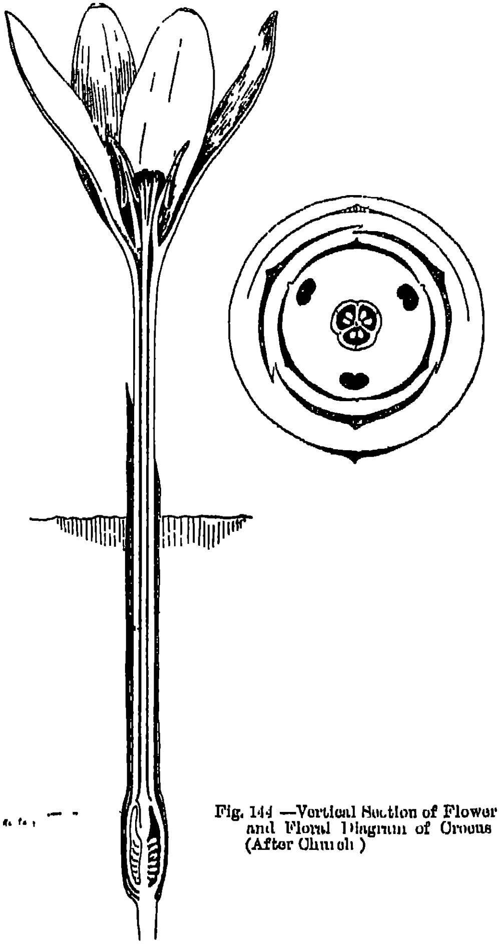


Fig. 144 —Vertical Section of Flower and Floral Diagram of Crocus (After Church)

Crocus plant in May or June, noting the swollen base of each shoot that has grown from a bud on the corm The latter is now withered and shrunken, while the swollen shoot-bases are fresh and plump Cut vertically through one of these swollen bases and note the solid white mass, which is obviously a *young corm* The young corm is formed by the swelling of the base of the stem, and its cells contain food which has been made by the leaves and has travelled downwards for storage in the young corm. Of what nature is the stored food in the Crocus corm?

The new corms continue to grow in size until the foliage leaves die and wither, when they will be found to have become as large as the parent corm (to which they are attached) was when planted Three or four, or even more, new corms may be developed in this way on the parent corm Gardeners usually dig up Crocuses after the leaves have withered, and the young corms, which readily break off from the old withered corm, are stored in a dry place until the time comes for planting them In this way the number of corms is multiplied, and in most cases gardeners do not trouble to raise Crocuses from seed Hence by the formation of corms the Crocus is not only enabled to last from year to year, *i e.* to become a *perennial* plant, the production of several new corms on each old one is a method of *vegetative multiplication*, *i e* increase apart from seeds

Now we can explain certain features of the dry Crocus corm What is the patch at the base of the corm? Simply the *scar* where it separated from its parent corm The brown stringy scales are, of course, the withered bases of the bud-scales and the foliage-leaves However, compare carefully the parts of the fresh young corm with those of (1) a dry corm, (2) a bud on a dry corm, (3) a shoot which has grown from a bud

Crocuses are divided into two groups according to the time of year when they produce their flowers. Some of the best known Spring-flowering Crocuses (flowers February to beginning of April) are *Crocus aureus*, the Common "Dutch Yellow", *C susianus*, the "Cloth of Gold"; *C vernus* (flower white or purple, leaves ribless), *C biflorus* (flowers white or lilac, leaves short erect narrow with white midrib). Among Autumn-flowering Crocuses are *C nudiflorus* and *C sativus* (Saffron Crocus), the latter is easily distinguished by its very large scarlet stigmas Spring Crocuses should be planted in the garden in September or October, Autumn Crocuses in July.

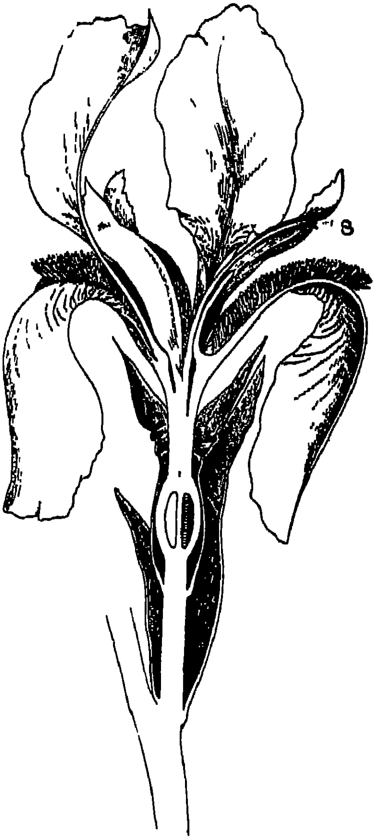


Fig 145.—Vertical Section of Flower of Iris (After Church.)

On the left are shown an outer perianth segment, a petaloid style entire, and an inner posterior perianth segment cut in half. On the right an outer anterior perianth segment and a style are cut in half showing a stamen lying between them; at the back is a lateral inner perianth segment (petal); s = stigma.

561. The Crocus and Iris Family (Iridaceae) is easily distinguished from other Monocotyledons by the petaloid 6-lobed perianth, the 3-chambered inferior ovary, and the 3 stamens (this marks it from the Daffodil Family—Amaryllidaceae — in which there are 6 stamens).

The order is divided into three tribes or sub-orders.

562. Crocus Tribe.—Flowers regular, terminal, single or with other axillary flowers (each in a spathe) produced in centrifugal order round the central flower; stem a corm.—*Crocus*. Two species of *Crocus* (*C. vernus*, *C. nudiflorus*) are "naturalised" in Britain, but not true natives.

563. Iris Tribe. Flowers, generally regular, in many-flowered inflorescences with spathes, each spathe enclosing several flowers; stem a bulb or rhizome.

Study the 2 British species of *Iris*.

Yellow Flag (*I. pseudacorus*), in wet places, has a stout creeping rhizome; leaves long, sword-shaped with "equitant" bases (V-shaped in cross-section and overlapping each other); fl. with a P-tube and 6 P-lobes (outer 3 ovate, spreading, 2 ins long, contracted at base into an erect broad claw, inner 3 smaller, oblong, and inclined upwards);

A3, opp outer P-lobes, style has 3 large petaloid branches, each covering a stamen and bearing on its lower side, just beyond the underlying anther, a small flap whose upper side is stigmatic Nectar is present at the base of the flower, secreted by the lower part of the perianth-tube, the larger outer perianth-leaves form a landing-place for the insect, which in probing for honey first touches the stigma The anther opens on its outer face, but as it lies below the stigma the entering bee touches the pollen after rubbing the stigma, and in retiring from the flower it pushes the stigma-bearing flap upwards, so that self-pollination is prevented; fruit a 3-valved capsule, seeds pale-brown, with hard coats See Fig 145

I foetidissima (**Roastbeef-plant**), in drier places, very common in S Eng, has narrower and shorter leaves; flrs smaller, outer P-lobes obovate and purple, inner yellow, seeds orange-red with fleshy coats

The numerous cultd Irises are divided into 2 classes—"bulbous" (with corms) and "tuberous" (with rhizomes), the former includes the so-called English Irises (*I xiphioides*), Spanish Irises (*I xiphium*), *I persica*, etc, while the rhizomatous Irises are classified according to whether the perianth-lobes have no "beard" of stiff hairs (*I sibirica*, *I pseudacorus*, *I foetidissima*, etc) or are bearded along the midrib, some having all the lobes bearded (*I falcifolia*, etc), most having only the 3 outer lobes bearded, either along both limb and claw (*I susiana*, etc) or along the claw only (*I. florentina*, *I germanica*, *I pumila*, etc)

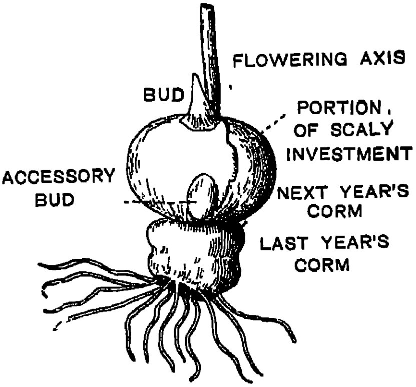


Fig 146 —Corm of Gladiolus after removal of enveloping scales

The Bud forms the Corm of next year, the Accessory Bud separates and forms a new plant.

[Tiger Flower (*Tigridia*, bulbous, cultd) differs from Iris in having P-tube very short, sta joined at base to form a long tube, style-arms slender and forked at ends, the large spotted yellow or orange flrs. last only about 12 hours] *Sisyrinchium* ("Blue eyed Grass," rhizome) occurs in bogs in Kerry and Galway, also cultd in gardens; P-tube short with equal spreading lobes, sta. joined at base, style-arms slender and unbranched (alt with sta). [*Libertia*, cultd., is similar to *S*, but sta free *Witsenia*, cultd, with thick rhizome and Iris-like leaves; P-tube long with equal lobes, style simple with 3 short stigmas]

564. Ixia Tribe.—Inflorescence as in Iris Tribe, but flowers often zygomorphic and each flower in a separate spathe; stem usually a corm. The only British species is the **Corn Flag** (*Gladiolus illyricus*), only in Hampshire.

Examine a cultd. *Gladiolus*, noting the large corms, which often remain connected in chains (Fig. 146). The perianth-tube is curved and the lobes unequal.

[*Ixia* (P-tube straight, slender), *Babiana* (P-tube funnel-like, throat dilated, lower lobes streaked and spotted), *Crocosmia* (P-tube curved, lobes spreading and star-like), *Schizostylis* (rhizome), have the P nearly reg., but the fl. is more or less distinctly zygomorphic (2-lipped) in *Tritonia* (= *Montbretia*), *Sparaxis*, *Anomatheca*, which have 3 simple style-arms, and in *Freesia* (P-tube long) and *Watsonia* (P-tube very short), which have each style-arm forked.]

565. Bluebell or **Wild Hyacinth** (*Scilla nutans*) is one of the most familiar of spring-flowering plants. It grows best in woods which are not *too* deeply shaded, but it sends up its leaves and flowers early in the year, thus gaining the benefit of the light and of insect-visits before too many other plants have joined in the competition. By the end of May, when the wood has become darker with the full foliage of the trees, the Bluebell has ceased flowering.

Note the long (9 to 18 ins.) and narrow (about ½ in.) leaves; the flowering shoot which grows, as a rule, beyond the leaves; the bell-shaped perianth, the six parts of which are free, or joined only at the bases; the stamens, one inserted on the base of each perianth-leaf. Below each flower there are paired bracts, which help to pack up and protect the flowers in the bud-condition. Note the blue colour of bracts, perianth, filaments, and pistil. The latter consists of a ribbed ovary (cut it across and note the structure), style, and three-lobed stigma (the lobes are often very faintly marked). Honey is found along the grooves which run down the outside of the ovary; the nectaries or honey-producing glands are in the partitions between the three chambers of the ovary.

The flowers are sometimes pink or even white, instead of having the typical blue-purple colour. The flower-stalk is erect until the flower opens; then it bends down and the drooping flower is protected against rain, which would spoil the pollen and honey; finally, when the fruit is ripe the stalk curves upwards again, so that the seeds are shaken out gradually from the three slits into which the capsule opens.

Visit plants at intervals, so as to observe all the changes which occur from the time the leaves and flowers emerge from the soil until the ripe capsule opens to let the seeds be scattered by the wind. Dig up a few plants each time you visit a place where Bluebells grow, a useful plan is to thrust sticks into the soil to mark the positions of the plants, so that you can get the underground parts after the leaves and flowering shoots have died down “The Bluebell is a plant which carries on a considerable part of its activity underground. At all times of the year some work is going on, and although much of it is hidden from view, a study of this underground history constitutes one of the most interesting phases in the life-cycle of the plant”[1]

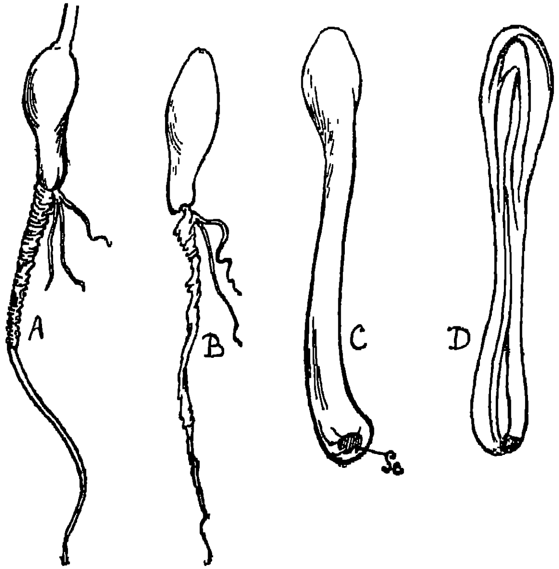


Fig 147 —Bluebell Bulbs
A and B show the wrinkled contractile root which pulls the bulb down into the soil

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[1] Woodhead, “Notes on the Bluebell,” *Naturalist*, 1904

Examine the swollen lower portion of the shoot, which often lies about a foot below the surface of the soil Tear off the thin outer scales (leaf-bases) which surround it, and note the white, sticky, fleshy scales which make up the greater part of the swollen mass. Cut (1) transverse and (2) longitudinal slices through this mass, and notice in the latter the small disc-like stem from which all the scales arise, and which bears roots on its lower surface and buds on its upper surface This structure is a **bulb** (Fig 147) It differs from the corm of the Crocus chiefly in the relatively smaller size of the stem, and in its investment by thick fleshy scales, which contain large stores of reserve food. In *scaly* bulbs (Lilies, Fig 148) the food-containing scales, of which the main bulk of the bulb is composed, simply overlap at their margins, whereas in *tunicated* bulbs (Bluebell, Onion, Hyacinth) the outer leaves are large and completely ensheath the inner portions of the bulb. The coloured membranous covering on the outside of such bulbs is formed by the shrivelled remains of the leaves of a previous season

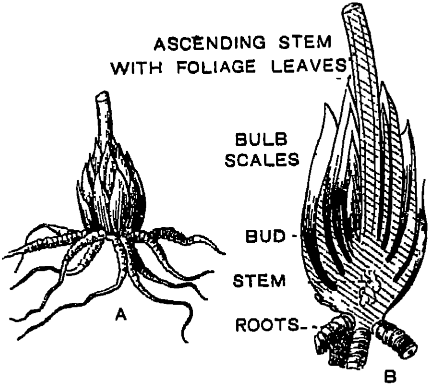

Fig 148 —Scaly Bulb of Turk's Cap Lily
A, Entire , B, Median Longitudinal Section

The bulb of a Garden Hyacinth, a Daffodil, and an Onion should be examined, since the parts are more easily observed than in the Bluebell. The bulb is largely composed of the enlarged persistent bases of foliage-leaves, but it also includes a certain number of scale-leaves A bud arises in the axil of the innermost leaf, and next spring this will develop into a flowering axis, surrounded by a number of foliage-leaves, and outside of these a few scale-leaves The outermost scales of the previous year shrivel, the inner ones persist, together with the bases of the foliage-leaves, and the enlarged axillary bud now forms the central portion of the new bulb. This may continue for several years,

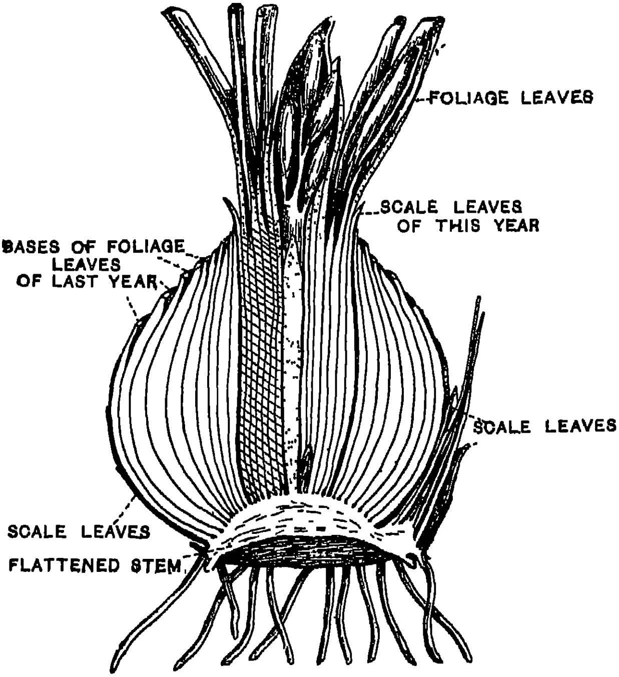
FOLIAGE LEAVES
SCALE LEAVES OF THIS YEAR
BASES OF FOLIAGE LEAVES OF LAST YEAR
SCALE LEAVES
SCALE LEAVES
FLATTENED STEM

Fig 149 —Vertical Section of Flowering Bulb of Hyacinth in Spring, with a lateral bud enclosed by a pair of scale-leaves

The shaded portion on the left marks this year's growth on that side. On the right the bud of next year is shown but ultimately two or more buds develop in the axils of the upper leaves As they grow they rupture the parent bulb, and are set free, after having absorbed a large amount of nourishment from it This is especially well seen in a Narcissus bulb Buds, composed of scale-leaves enclosing foliage-leaves, may also develop in the axils of the outer scale-leaves See Fig 149.

We saw that the Crocus corm contains abundant starch. what reserve food is present in the Bluebell and these other bulbs? On testing a sliced bulb with iodine we find that the Bluebell contains very little starch, the Onion none at all The chief food stored in the Onion is *sugar*, as can be proved by means of Fehling's test, while the Bluebell bulb contains chiefly a carbohydrate substance called *inulin*, which resembles starch in composition but is soluble in water (less so than most sugars, however)

The underground life-history of the Bluebell is very interesting, and the main points, as regards external features at any rate, are fairly easy to make out Young seedlings can be dug up in October or November, older ones in May and June, but if you cannot find the seedlings in the soil bring some capsules home and sow the black globular seeds. The germination is similar to that of the Onion

566. The Lily Family (Liliaceae) consists chiefly of perennial herbs with bulbs (Lily, Onion, Hyacinth), rhizomes (Solomon's Seal, Lily of the Valley), or corms (Meadow Saffron), but the order also includes a few shrubs (Butcher's Broom) or even trees (*Yucca*, *Dracaena*) The Butcher's Broom has flat green branches (cladodes), and the true leaves are represented by small scales, it flowers throughout the colder months of the year, the flowers (borne on the cladodes) usually being *dioecious* (some with stamens only, others with pistil only). Asparagus also has small scaly leaves and tufts of green (generally needle-like) branches which carry on the functions of foliage-leaves; sometimes these cladodes are flattened That the cladodes of Butcher's Broom and Asparagus are really branches is shown by the fact that they bear flowers, and that they arise in the axils of scales (the true leaves) on the stem.

The flowers are regular and hypogynous. The flower-parts outside of the stamens are all coloured, and do not differ much, if at all, in form, they are therefore said to form a *perianth* The perianth nearly always consists of six parts, rarely of eight parts (*e g* Herb Paris, Aspidistra), and usually there is a division into three inner and three outer parts There are usually six stamens, arranged in two series (whorls), outer and inner The pistil usually consists of a three-chambered ovary with numerous ovules in each chamber, a single style, and a 3-lobed stigma Note that in Bluebell and Tulip the perianth-parts are free from each other, whilst in the majority of Liliaceae (Fig 150) they are carried up as lobes on the margin of a tube, the stamens being inserted on the inner side of the tube

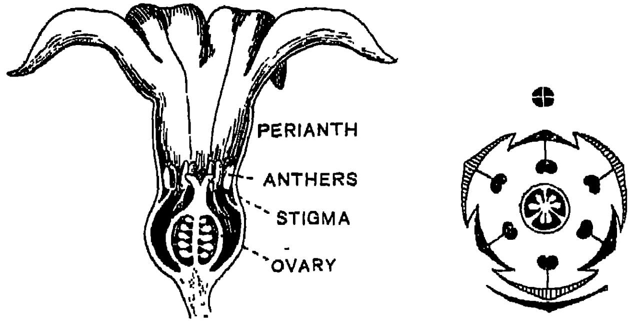

Fig 150 —Longitudinal Section and Floral Diagram of Flower of Garden Hyacinth

Both self- and cross-pollination occur, most of the flowers being adapted for long-tongued insects In Aspidistra ("Parlour Palm"), which belongs to E. Asia, the flowers are produced close to the ground, and are pollinated by small insects which creep through openings between the four large stigma-lobes (according to some accounts the flowers are pollinated by snails) In most Liliaceae honey is produced by glandular tissue in the partitions between the chambers of the ovary In *Colchicum* honey is secreted on the outer side of the filaments of the stamens, at the bases of their free parts, not in the long perianth-tube In Tulip and Garlic there is no honey, but the flowers are visited for pollen. In Herb Paris the dusky colour and fetid smell of the flower attract carrion-loving flies, which alight on the stigma and then crawl over the anthers, becoming dusted with pollen.

The fruit is either a capsule or a berry, and the seeds are endospermic, the endosperm generally contains oil and proteids and the cell-walls are thickened (cellulose).

The order is divided into numerous tribes, some of which are not represented in Britain The British Liliaceae may be roughly divided into (1) bulbous plants, (2) rhizomatous plants

567. Of Brit Liliaceae with bulbs, *Allium* (**Garlic**) has flrs. in umbels or heads (enclosed at first in a scaly 2-leaved involucre) on long flowering stems , *A ursinum* (**Ramsons**) is common in woods The others have flrs in racemes , *Fritillaria* (**Snake's-head,** flrs. large, drooping, P-leaves free, purple with square whitish dots), *Tulipa sylvestris* (**Wild Tulip,** flr yellow, erect, P-leaves free recurved), and *Gagea* (**Yellow Star of Bethlehem,** P-leaves free spreading, flr small), all rare in Brit , have leaves on the following stem The leaves are all "radical" in *Scilla* (2 rare species in Brit. besides the common Bluebell), *Ornithogalum* (**Star of Bethlehem,** flrs white, P-leaves free spreading), and *Colchicum* (**Meadow Saffron,** flr. lilac, P-tube very long)

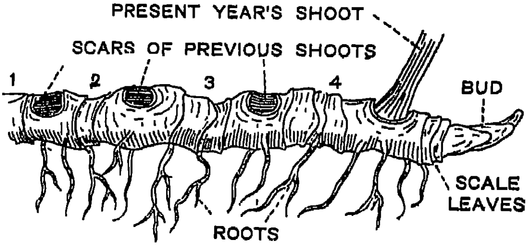

Fig 151 —Rhizome of Solomon's Seal

The numbers represent increments of successive years

568. *Ruscus* and *Asparagus* have cladodes (flat, ovate, spiny-tipped, and basally twisted in *R.*, needle-like or linear and in tufts in *A.*) ; flrs polygamous, small, greenish , fruit a small red berry , *R.* flrs. Nov -Apr , *A* June-Aug

Paris, in woods, sends up flowering shoots with 3-8 (gen. 4) ovate net-veined leaves in a whorl below the flr. , P gen. 4 + 4, outer green, inner yellowish, A = number of P-leaves ; berry black

Solomon's Seal (*Polygonatum multiflorum*), in woods, has a thick rhizome (Fig 151), sending up each year a leafy shoot ; leaves alt., ovate, all turning to one side, flrs. 2-8 in leaf-axils, drooping on lower side of shoot, P-tube bell-like, white, berry bluish-black.

The leaves are all "radical" in **Lily of the Valley** (*Convallaria*, in woods, not common, flrs. in a raceme, white, drooping, P. bell-like with recurved lobes, berry red) and **Bog Asphodel** (*Narthecium*, very common in bogs and marshes, leaves stiff and acute, flrs. erect, golden yellow, sta. with white hairy filaments, red capsule, narrow seeds with a hair at each end).

569 Notes on Common Cultivated Liliaceae.—Most of the genera repd. in Brit. are cultd. in gardens.

In *Lilium* (bulbs, leafy stems, flrs. in racemes) honey is secreted in grooves at bases of P-leaves, *L. martagon* (Turk's-cap, found naturalised in parts of Brit.) is scented at night only, *L. bulbiferum* produces bulbils in the leaf-axils, many species are adapted for pollination by butterflies and moths, and in most species with drooping flrs. the stalk becomes erect so that the seeds are only let out when the capsule is shaken.

Fritillaria imperialis (Crown Imperial) has a tuft of leaves at top of stem with a whorl of flrs. below. In Tulip, note the wax-covered unwettable leaves with concave stem-clasping bases, the free P-leaves which close at night and in bad weather, erecting of the ripe capsule, the flat seeds. *Erythronium* ("Dog's-tooth Violet") has same habit as *Tulipa*, single large drooping flr., oblong leaves, P-leaves free (inner ones each with a tooth on each side). *Calochortus* (Mariposa Lily) has rigid sword-like leaves, flr. cup-like, P-leaves free (outer narrow, inner much larger and hairy inside), stigmas sessile on ovary. Many species of *Scilla* are cultd., mostly with blue star-like flrs., P-leaves free.

Hyacinthus (the garden Hyacinths, derived from *H. orientalis*) differs chiefly from *Scilla* in having the P-leaves more or less joined at base, as they are in the 4 following allied genera: *Muscari* (Grape Hyacinth), with nearly globular flrs. (upper flrs. of raceme neuter—cf. flr.-head of Cornflower), *Chionodoxa* (Glory of the Snow, small blue flrs. in early spring), *Lachenalia* (small plants with yellow or red flrs., capsule 3-winged); *Galtonia* (long flowering shoot with terminal raceme of drooping white scented flrs.).

Gloriosa has branched aerial shoots, lanceolate leaves each ending in a tendril, flrs. solitary in leaf-axils, drooping, with sta. and style projecting horizontally, anthers versatile; seeds with a fleshy red coat, poisonous. *Veratrum* has a rhizome (that of *V. album* = "white hellebore root," poisonous) and broad-ovate leaves, flrs. in racemes, lower ☿, but upper ♂ (some plants with only ♂ flrs.).

Asphodelus has awl-shaped or Iris-like leaves, small white flrs. in dense racemes, protogynous, P-lobes equal and spreading. *Funkia* has stalked ovate or cordate "radical" leaves, tubular P, blue or white, seeds with an apical wing. *Hemerocallis* (Day Lily) has large trumpet-like yellow or orange flowers in corymbs, and long leaves, the flrs. are self-sterile and short-lived. *Eremurus*, allied to *Asphodelus*, has very protogynous flrs. (yellow or white in terminal raceme), and the P-leaves wither before the stigmas are ready for pollination.

Anthericum, a large genus, has flrs (gen white) in racemes, linear hairy or fleshy leaves, P of spreading or bell-shaped equal segments, sta with short filaments, stigma spherical *Bowiea* has a large corm, much branched, twining green aerial stems with small leaves which soon fall off *Aloe* has a woody branching stem (often very short); evergreen fleshy leathery leaves (often spiny), in rosettes, flrs in spikes, drooping, P tubular with exserted sta *Kniphofia* (= *Tritoma*) has similar spikes of red or orange flrs, but the leaves are thin and grass-like, not fleshy *Phormium tenax* has stiff Iris-like leaves, the bundles (veins) of which have tough sclerenchyma-bands yielding valuable fibres (New Zealand Flax), *Xanthorrhea*, also an Australasian desert-plant, has a thick stem covered with leaf-bases, long wiry grass-like leaves, and a long-stalked (up to 20 ft) cylindrical spike of flrs with scaly perianths

Several species of *Allium* are cultd for their flrs, more for cooking purposes (garlic, onion, leek, shallot, etc), some (e g onion) have cylindrical leaves, some have the flrs replaced by bulbils *Agapanthus* (Love Flower) has blue flrs in umbels, with short P-tube and spreading lobes, seeds winged *Brodiaea* is similar, but 3 of the sta are sterile (repd by scales)

Asparagus is cultd for its feathery "foliage" (cladodes, gen needle-like, but flat in some species), also for its young shoots which are cooked. *Aspidistra* ("Parlour Palm") has curious brown flrs, P (8), A 8, G (4); it is perhaps the hardiest of all indoor plants and has large oblong pointed leaves, often with white stripes *Yucca* (Adam's Needle, often cultd), *Dracaena*, and *Cordyline* are Palm-like shrubs with stiff fleshy leaves, flrs bell-like, sta gen with filaments, flat and broad below anther, capsule with ∞ seeds

Smilax, a large genus, has net-veined cordate leaves, mostly with 2 tendrils (= stipules?) at base of leaf, stem often with recurved prickles to help in climbing, flrs unisexual, in umbels, ♂ and ♀ on separate plants, berry with 1-3 seeds, the "sarsaparilla" of druggists consists of the dried roots of several species of *Smilax* *Ophiopogon* has numerous linear leaves and a long flowering-shoot bearing axillary cymes of flrs, P-tube short and cohering to ovary, with spreading lobes *Aletris* ("Star-grass") has lanceolate leaves, white bell-shaped flrs in racemes, outer surface of per mealy; P. tubular, enclosing capsule *Lapageria rosea*, much cultd in greenhouses, is shrubby, with twining stems, alt ovate leaves, and large axillary flrs. with bell-shaped per, berry edible

570. The Daffodil Family (Amaryllidaceae) differs from Liliaceae in having the ovary inferior instead of superior In the Daffodil and other species of *Narcissus* there is a series of membranous outgrowths on the inner surface of the perianth, just below the free lobes of the latter These outgrowths form a tube or *corona*, which is short in some Narcissus flrs, but in the common Daffodil attains a considerable length In the Snowdrop (*Galanthus*) and the Snowflake (*Leucojum*) there is no corona, and the parts of the perianth are free

This is a large and widely distributed order, usually occurring in dry sunny habitats. It includes many showy garden plants (*Zephyranthes*, *Ixiolirion*, *Amaryllis*, *Crinum*, *Alstroemeria*, *Clivia*, *Pancratium*, *Nerine*, *Haemanthus*, etc.), also the large "American Aloe" (*Agave*) See Fig 87.

QUESTIONS ON CHAPTER XXIV

1 Describe, with sketches, the structure of a resting Crocus corm

2 Give a clear account, from your own observations, of the events which occur from the time a resting Crocus corm is placed in moist soil or sawdust, up to the time when the leaves die down Include the changes that occur below as well as above the soil, and give a series of sketches

3 For how many days does a Crocus flower last, from the time when it first opens?

4 Describe observations and experiments you have made on the opening and closing of the Crocus flower

5 What other flowers with which you are familiar open and close like the Crocus flower?

6 Draw a floral diagram of any flower belonging to the Order Iridaceae, and describe fully its pollination Name the chief points of difference in the structure of such a flower and a tulip flower

7 Describe the structure of the flower of Bluebell, and compare it with that of a Garden Hyacinth

8 What other flowers besides those of Bluebell droop when they open? How is the drooping caused? Can you explain why so many spring flowers either droop or have the power to open and close? Give a list of spring flowers which droop and of those which perform opening and closing movements

9 Describe, from your own observations and dissections, the structure of a Garden Hyacinth bulb Sketch, on a large scale (about twice the natural size), a longitudinal section made through the centre of a bulb, marking all the parts shown.

10 Describe and explain the structure of a Narcissus bulb, with the smaller bulbs attached to it How is it that some scales go round the whole set of bulbs?

11 Describe carefully all you saw when growing a Hyacinth bulb in soil, sawdust, or water, and explain the things you saw. Give sketches

12 Describe the whole of an Early Purple Orchid plant as seen when in flower in early summer, omitting the flowers themselves

13 Describe, from your own observations, the growth of an Early Purple Orchid from the time when its leaves first come above ground until they die down When did you first see the leaves, and when do they die down?

14 Describe, with sketches from actual specimens examined, the flower of the Early Orchid, and explain its adaptations for pollination Describe experiments you have made with the flowers

15. Compare the following plants with regard to the nature of their reserve food and that of the food-storing organs —Crocus, Bluebell, Garden Hyacinth, White Lily, Orchid, Onion

CHAPTER XXV.

TREES AND SHRUBS

571. Trees and Shrubs.—There is no sharp distinction between herbaceous and woody plants, though the terms herb, shrub, and tree are convenient for general use It is perhaps sufficient to define a woody plant as one whose stem persists above the soil year after year (as compared with a plant which dies down to the level of the soil, though the "root-stock" or rhizome is hard and woody), storing food in its stems and buds and the latter being protected in most cases by special scales

A tree usually possesses a stout, main trunk from which smaller and more slender lateral branches arise Frequently, however, the main stem is short, and is exceeded in length by the branches A shrub, on the other hand, is simply a miniature tree, the primary stem being usually short, and soon breaking up into numerous more or less erect lateral branches.

Various plants which form large trees when growing in sheltered or low-lying places are reduced to stunted shrubs when they occur on high mountains or wind-swept ridges On Dartmoor, for instance, there are several patches of gnarled and stunted oak trees, doubtless of great age, growing among granite boulders along river valleys, at a height of about 1,500 ft On several "tors" (granite-caps on hills) there grow Rowan (Mountain Ash) plants reduced to low-creeping shrubs a few inches high, in one case the flat top of a tor, about 1,800 feet above sea-level, was covered with this dwarf Rowan

In studying trees the following points should be attended to (full notes and sketches being made in each case) :—

(1) The general form and appearance as determined by the mode of branching, direction of the branches, and the character of the foliage.

(2) The nature of the situation and the character of the soil in which each species apparently thrives with the greatest luxuriance

(3) The general effect of each kind of tree on the appearance of the landscape in winter, spring, summer, and autumn

(4) The thickness of the trunk as compared with the size of the tree, the character of the bark; the arrangement, direction, and surface of the branches

(5) The time of the appearance of the leaves, their arrangement, the form of the leaf, and the arrangement of the veins

(6) The time of flowering, nature of inflorescence, position and mode of protection of flower-buds, structure of the flowers and their pollination

(7) The nature of the fruit and seed and the mode of dispersal

(8) The germination of the seed and the form of the seedlings, which may often be found under the trees or at some distance from them, gather ripe seeds and study their germination

(9) Kinds of insects, if any, that feed on foliage or produce galls, insects, if any, that visit the flowers, fungus-parasite, if any.

(10) Name of tree or shrub (scientific and common names), Natural Order

Note whether the main trunk persists and runs up through to the top of the tree ("excurrent" or "spire-forming" habit, *e g* Larch) or whether it soon becomes lost in a complex of strong branches ("deliquescent" or "diffuse" habit, *e g* Beech), the form of the tree's crown, whether pointed, rounded, or umbrella-like, the arrangement of the branches, the angles at which they come off, their direction of growth; why branches at the top of a tree are usually more straight than the lower branches, why branches turn up at the ends in many trees, why branches rise upwards, or bend in towards the centre of the tree in winter (in deciduous trees) All these points, which, together with others, unite to give trees their general form, should be carefully studied In many cases this is more easily done in winter, when deciduous trees show their bare branches

Note also the depth of the shade cast by the tree when in full foliage, and the effect this has on the nature and habit of the plants forming the undergrowth, the mode of branching shown by the tree when growing with others in a clump or in a wood, and that shown by the same kind of tree when growing by itself in an open situation, the differences in size and in texture of the leaves well exposed to light, and of those growing in shade; the tendency of the leaves on each twig to form a "leaf-mosaic" (*i e.* to vary in size and shape so as not to shade each other); the structure of the winter-buds, and the various ways in which the young leaves are folded up and protected

Some further points relating to the biology of trees may be mentioned here One often sees on high exposed places inland, as well as near the coast, trees which have grown obliquely, sometimes almost horizontally, after reaching a certain height, in other cases the trees growing in such situations are erect, but growth has occurred almost entirely on one side If you see examples of such trees, try to discover the causes of their bent or one-sided growth Note the direction of the bend or that of the well grown side of the tree, then find out the directions and characters (whether dry or moist, cold or warm) of the prevailing winds At what time of year will the prevailing wind have most influence on the tree's growth, and in what way?

572. How Wounds Heal.—You will often notice on the trunks of trees curious ring-like cushions It is easy to find out the meaning of these cushions and to trace their history, especially if you have seen foresters at work cutting off branches Under whatever circumstances and for whatever reasons (find out all you can on these points) this "tree surgery" has been practised, the amputation-wound soon begins to heal up, under proper conditions The cambium (Art 300), which has been exposed by the cutting, produces a mass of growing tissue, known as **callus,** which in time rolls over and covers the wounded wood (which cannot heal of itself) If the wound is a small one, the callus-cells soon meet at the centre and form a continuous tissue which produces cork at the surface and (being continuous with the ordinary cambium) wood internally, covering up the stump

The callus protects the exposed wood by excluding water, bacteria, and fungi, which set up decay, all exposed surfaces, whether caused by pruning-knife or saw or by the breaking off of branches, offer a foot-hold for disease and decay, and once a wood-rot fungus enters it may grow inside the tree after the wound is quite covered. Hence, for the wound to heal properly and as quickly as possible, the limb to be removed should be cut off close to and perfectly even with the parent trunk or branch, so that no portion of the amputated branch may remain An exposed stump or stub left when a branch breaks off cannot possibly heal over of itself, and if it project far from the trunk or branch, the cambium or inner bark cannot produce enough callus to cover and protect it, so that decay of necessity sets in, and the stump dies back, possibly to communicate disease to the trunk, even if it does heal up at the base, a bad knot is formed in the timber A clean-cut, smooth and hard surface, such as is produced by a sharp pruning-saw, is much preferable to a rough and jagged one, since it affords less lodgment for water or germs, avoids crushing or tearing of the cambium, and assists the progress of the protecting and healing callus.

In the case of a *large* wound, cork and new cambium are produced by the callus at the edges of the wound, which does not close up until cushion after cushion of callus has grown over it, and this may take several years Though the growth of the callus cannot be hastened by "dressing" the wound, the latter can be protected from moisture and fungus spores by applying tar or lead-paint

The old wood exposed by the wound, which generally becomes dark in colour, does not grow with the new wood formed by the callus,

hence a deep cut—*e g.* an inscription—made in the wood of a
be found years afterwards, covered by annual layers of new
Any hard body, *e g* a nail or the stem of another tree, may be
in a tree by causing the cortex to split and a callus-layer to be
which grows over the body and covers it with new wood.

Wounds made in herbaceous stems, roots, tubers, leaves, frui
are healed in a much simpler way In general, whenever th
tissues are laid bare by injury a layer of cork is formed by the
cells which are living and capable of growth, the wounds cov
this way are easily recognised by the brownish patches of c
potato-tuber, for instance, is covered by a layer of cork, and a
layer is soon formed on a piece cut out of the tuber and kep
a bell-jar or tumbler, try this simple experiment, and if you
microscope cut sections to see the cork-layer in (1) an uninjured
(2) a piece cut out and allowed to heal

Familiar operations which depend upon callus format
(1) pruning, (2) grafting, (3) budding, (4) propagation by cuttin

573. Pruning, as applied to fruit trees, is of the
interest to the botanical student as well as to the
grower—both commonly ignorant as to the "reason
of such operations One of the chief points to remem
that all parts of the tree should receive plenty of lig
air, because the formation of flower-buds, and there
fruits, depends largely on the proper action of the leav

It is, of course, essential to be able to distinguish the "frui
i e flowering-buds, and to know on what part of the tree t
usually borne The flower-buds are easily recognised, long befo
open, by being larger and more rounded than the "leaf-bu
vegetative buds, in Apple, Pear, Plum, and Cherry they
"spurs" (short and slow-growing branches or dwarf-shoots)
twigs of the previous year or years, and mostly at the ends of th

As a rule, each spur or spur-branch of large-fruited trees (*e g*
Pear) fruits every alternate year, because the ordinary food su
insufficient to nourish the fruit and a new fruit-bud, which
usually formed till the following year, and which fruits the ye
its formation The removal of all the flowers or very youn
from part of the spurs of a tree, or from certain branches, enc
the fruiting of the pruned parts the following year, and so tend
up an annual bearing habit, some portion of the spurs and b
fruiting while the remainder are forming fruit buds to bear the
ing year

Trees which from some cause or other do not come into bear
often be induced to form fruit-buds by judicious pruning.
checking growth induces fruitfulness, it does not maintain
when once bearing is established it must be preserved by prop
and the avoidance of any disturbing element, such as heavy pru
the bearing of too heavy a crop

The younger a shoot, the more rapidly and completely it heals, so that shoots which have to be removed should be pruned as young as possible The healing process cannot begin during late autumn or winter, as the cambium is then practically dormant The best season therefore for pruning woody portions of trees is immediately before growth begins in spring, and while the trees are yet dormant, the more rapidly a wound heals, the less is the chance of decay obtaining a foothold Some people prune in autumn, before the leaves have fallen, because the presence of the leaves enables one to decide more easily upon the density of the tree

Those trees which bear their fruit on shortened spurs often produce a large number of useless shoots, and if these are retained until the autumn a great deal of valuable time is lost to the tree Sunlight is prevented from gaining access to the leaves in whose axils the blossom buds are being formed, and this seriously affects their development By a timely removal of superfluous growth far more blossom buds are also produced The importance of summer pruning is thus clearly seen in such a case

Pruning is an art which requires great skill, it is necessary to know whether one is pruning (1) for increased wood-production, (2) to induce or increase fruit-bearing, (3) to remove injured, decaying and superfluous parts, (4) to train or restrict the tree to any desired shape and size, or (5) to ensure larger or better fruits

The effects of pruning in hastening or increasing productiveness are sometimes augmented in garden practice by bending or twisting the shoots, notching or ringing

574. Bending a shoot horizontally results in the supply of water being diminished along its entire length, as the bend retards its flow Every considerable bend in a branch acts as a partial barrier to the upward flow of the sap and to the descent of assimilated food matter, which latter accumulates above the bend and causes the development of flower-buds Twisting a shoot is a more energetic means of effecting the same end

575. Notching is often used to force the development of particular buds in trained trees In such cases the notch is made in the bark and young wood immediately above the selected bud The notch so made checks the upward flow of sap, and so induces rapid elongation of the bud into a shoot Notching into the wood below a bud stops the downward passage of elaborated food material, the store so created encouraging the formation of fruit-buds. The size of the notch varies with the size of the branch, a narrow notch being ample for small shoots, while half an inch width is not too much for a large branch.

576. Ringing is effected by cutting through the bark completely round the stem or branches of a tree, to keep the food elaborated by the foliage from descending beneath the ring This results in inducing bearing, and in hastening the production of larger fruits The operation is effected as growth begins in spring by drawing a knife round the branch or trunk so as to cut entirely through the bark, from an eighth to a quarter of an inch of which is sometimes removed As a rule, ringing is only resorted to when a well established tree cannot be brought into bearing by other means

577. Grafting consists in placing together the cut surfaces of two different plants, which must belong to the same family (*e g.* Rosaceae), in such a way that they unite by the growing together of their cambium tissues The rooted plant which is to receive the graft is called the **stock**; the cutting which is applied to the stock, and which consists of a twig bearing buds, is called the **scion.**

The chief objects of grafting are (1) to make use of the age and strength of a cheap or easily obtained or exceptionally vigorous stock in order to obtain quickly the fruits (or flowers) produced by the plant from which the grafts are cut, (2) to ensure the exact perpetuation of varieties of fruit trees, (3) to multiply them more rapidly than would be possible by seeding or cuttings, and (4) to produce desired changes of a radical nature in habit of growth or character of scion or stock (as when apples and pears are dwarfed by working them respectively on the Paradise and Quince stocks)

Success in grafting depends largely on the work being done when the sap of the stock is in motion (best during spring at the season of greatest growth, when Nature most readily repairs injuries), as also on the health and vigour of both scion and stock Wounds made in grafting are covered with wax to exclude disease germs and prevent evaporation from the wounded tissues

The scions or grafts are usually cut in autumn from wood of the previous year's growth, with plump and well-formed buds, and stored (tied in bundles and packed on end) in damp moss, sand, soil, or sawdust The scion may be inserted in the root, trunk, crown, or any of the branches of the stock

Whip or **Tongue Grafting,** the commonest method, is usually practised only on small stocks up to about two years of age, and like the method next described is specially suitable for cases where scion and stock are of equal size Both scion and stock are cut across diagonally A vertical cleft is then made in each, and the two parts are dove-tailed together by pushing the tongue of the scion into the cleft of the stock They are held firmly in position with five or six turns of raffia, and the whole of the wound is protected by wax applied over the ties

Splice Grafting, the simplest form of grafting, is suitable only for small shoots It is effected by cutting scion and stock across obliquely with a sharp knife, placing them together as exactly as possible, and fastening them with raffia, over which a coating of wax is applied as in Whip Grafting

578. Budding consists in taking a single bud from the tree which it is desired to propagate, and placing it in contact with the cambium of the growing tree which is to serve as parent or stock It is used in the propagation of Roses and fruit-trees (Apples, Plums, Pears, etc.), also for multiplying choice varieties of ornamental trees (Maples, etc) It is generally performed in early summer or early autumn, but sometimes in early spring (as soon as the bark of the stock loosens and peels easily on being raised) with resting buds taken in autumn or winter, and kept in a cool place with their ends set in soil (as with scions for grafting) It is better, as a rule, to cut the selected shoots fresh when the buds are required, plump (not bursting) buds from near the centre of vigorous shoots of the current season's growth are best

In **shield-budding** a shield-shaped portion of bark, with a thin shaving of wood, is taken from the shoot with each bud, by a clean cut in the direction in which the shoot grows A vertical slit about an inch long is cut just through the bark of the stock and a horizontal slit of half an inch across its highest point, the two cuts forming a T The corners of the stock-bark are raised with the blade or the flat scalpel-like handle of the budding knife, so as to admit of the free passage of the bud, which is now inserted under the bark at the transverse cut and pushed downwards under the edges of the vertical slit with the fingers, and then with the knife handle until the bud has passed well down into the cleft, with its inner surface pressing against the bared wood of the stock Any portion of the shield bark projecting above the transverse slit must be cut off exactly even with it

The success of budding largely depends on its being done when bark rises freely, so that little use need be made of the knife-blade or handle in lifting the bark at the edges of the vertical cut The tying material, usually about a foot in length, is laced, securely but not too tightly, twice below and thrice above the bud, which must not, of course, be covered with the tie

The inserted bud sticks to the stock after about two to three weeks, and the ties are then cut through on the opposite side of the stock to the bud, so they may freely drop off at their own time The constriction caused by leaving the strings uncut for too long a time may result in killing the bud, or in making it start to grow too soon. The bud should remain fresh, but dormant, until the following spring, those breaking into growth earlier are injured, if not destroyed, by winter cold Such growing shoots should be cut back before winter if long enough, buds that shrivel and turn brown are failures, and the stocks will need re-budding

The stock is cut off four or five inches above the bud in the spring following budding as soon as it shows signs of activity This is done to concentrate all possible energy into the bud When this has grown out from one to two inches, the stock is again cut back, to half an inch above the bud All sprouts must, of course, be kept rubbed off the stock, and the bud should be trained out into a single stem in line with the stock

In **Ring- or Flute-Budding** two horizontal cuts are made round the scion in spring when the sap is in motion and the bark peels off easily, one incision being above and the other below one or more buds A downward slit is then made connecting the two horizontal cuts, and the piece of bark is removed, and quickly set round the stock in place of a corresponding portion of bark previously cut from it The fresh bark is tied in position, and may with advantage be waxed over its edges

579. Propagation by Cuttings (Slips).—Most woody plants, and many herbaceous ones, are readily propagated by means of cuttings or "slips." The cutting is stuck in the soil (or in water, Fig. 70) and from its lower end roots grow out, above the cut surface as well as at its edges.

Make cuttings of various plants and place them in moist soil, tying them to supporting sticks. Keep some in darkness, others in light; keep some in a warm and others in a cold place, water some freely, others sparingly Compare the growth of the cuttings in each case, trying both woody and herbaceous shoots, keeping notes of the results In some cases cut the stem straight across, in others make a long slanting (oblique) cut

In a woody cutting that has been inserted in the soil for a week or two, note on the lower end (1) the pith and wood, now dead and discoloured, (2) the callus, forming a circular cushion, (3) the roots arising from the callus, (4) the roots arising from the stem above the cut and bursting through the rind. Split the cutting lengthwise an inch or two from the base, and note (1) the wood, black and decaying for some distance upwards, (2) the callus covering the cortex and edges of dead wood, (3) the bases of the roots which arise in the cambium.

In propagation by cuttings the objects aimed at are (1) to induce the rapid healing of the cut, which is effected by the formation of a cushion of callus on the surface of the wound, (2) to induce the formation of (adventitious) roots on the cutting, and thus enable it to become an independent plant. For these processes to occur there must be a sufficient amount of food available at the seat of growth.

In woody plants, e.g. Roses, enough food is already present, stored in the stem-tissues (cortex, bast, and rays), the cells of which, on absorbing water, expand and divide to form a mass of growing tissue, driving the wounded and dead cells off at the surface as a cork-layer, while the inner callus-cells form a cambium (continuous with the ordinary cambium of the stem) which produces new wood and bast as well as roots.

Cuttings of herbaceous plants are often distinguished as "slips", Geranium (*Pelargonium*), Fuchsia, Coleus, Chrysanthemum, etc., are propagated in this way. The gardener chooses shoots which break off squarely on being bent (if the stem bends or crushes it is either too old or too young for good results) and usually cuts the stem below a bud. In herbaceous cuttings the stem contains very little reserve food, and the pith takes an active part in the formation of the callus.

See Questions 11-15 at the end of this chapter—a few examples of the numberless questions relating to horticultural practice that might be asked and can only be answered from knowledge gained by experimental study.

The remainder of this chapter deals with common, native and introduced, Dicotyledonous trees and shrubs.

580. The **Poplars** (*Populus*) and the **Willows** (*Salix*) are closely allied, forming a family (**Salicaceae**) which is sharply marked off from all other catkin-bearing plants. A catkin is simply an inflorescence consisting of a main stem or axis which bears either male flowers or female flowers, each flower arising in the axil of a leaf (bract) and having a very simple structure. The male and female catkins are on separate plants.

581. The best known Poplar is the **Black Poplar,** which we shall take as a type for first study. The main part of the root system grows deep into the soil, but some of the roots run along, more or less horizontally, a little below the surface The shallow roots often send up leafy shoots ("suckers") The tree is rarely over a hundred feet high, most of the branches bend upwards, and the tree has a loose appearance and a "lopsided" crown

The leaves (Fig 152) have long stalks and the upper part of the stalk flattened at right angles to the blade, so that the leaf hangs loosely and quivers in the gentlest wind It has been suggested that two advantages arise from the tremulous character of the leaves in this and several (not all) other Poplars —(1) the resistance offered to the wind is lessened, so that the thin twigs can better withstand the strain, (2) the evaporation of water from the leaf is increased, an advantage in rapidly-growing trees with a good water-supply from below. The first suggestion is supported by the fact that in Poplars with *thick* twigs, *e g* Lombardy Poplar, the leaf-stalks are not flattened, the second by the fact that Poplars "prefer," *i e* thrive best in, deep moist soils

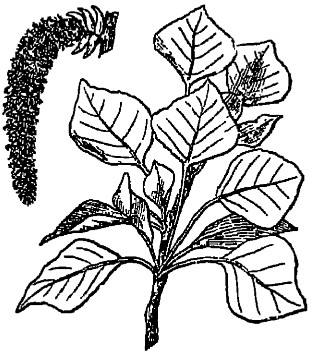

Fig 152 —The Poplar Twig and Male Catkin

The leaves vary in shape, but the margin of the blade is always regularly toothed, its upper and lower sides are almost the same colour, and it has no hairs—these points distinguish our type from other Poplars The tree sheds not merely its leaves, but whole twigs, sometimes as long as six feet, an abscissa-layer (Art 155) is formed just as in the case of a leaf, so that a clean cork-covered scar is left when the twig is cast off

The buds are long, pointed, smooth, each has four scales—an outer concave scale on the side away from the stem and three inner ones In spring these scales fall off, together with the stipules of the sticky young foliage-leaves The side buds generally grow into dwarf shoots or into catkins, while the end bud grows into a long shoot The highest bud is not really the end bud, as in many other trees, the real end bud does not develope at all, the highest axillary or side bud replacing it in growth

The long hanging catkins open before the leaves unfold. Each catkin is produced from a special bud, which resembles an ordinary bud in having four scales. The bracts are fringed at the free (outer) edge, but are not hairy Each flower has a short stalk bearing a shallow lop-sided cup-like organ

In a male catkin we find within this cup a tuft of stamens (about forty), each with a red anther At first the male catkin is erect or horizontal and the filaments are very short, but soon the catkin-axis lengthens, the catkin droops, the bracts fall off, and the filaments rapidly grow longer and push out the anthers Then the anthers open and shed the pollen, which is carried by the wind, and soon the catkin falls off the tree—usually before all the anthers have opened

In the female catkin the cup surrounds the base of the pistil, above the ovary (one-chambered, with numerous ovules in two lines on the wall) are two large yellow branched stigmas After pollination the axis of the catkin lengthens and the ovary grows into the fruit (capsule), which splits down along two lines halfway between the two lines of seeds, then the two valves roll outwards and the seeds escape Each seed has a tuft of hairs arising from its stalk and serving for wind-dispersal.

For a comparison of the flowers of Poplars and Willows see Art 357

582 The **Lombardy Poplar** is simply a "pyramidal" variety of the Black Poplar, distinguished by its deeply furrowed bark and especially by the strong tendency shown by the branches to bend upwards and grow erect Connected with this peculiar habit, which enables one to recognise the tree from a great distance, is the fact that only the buds on the *outer* side of the tree, *i e* those which are most exposed to light, grow out to form shoots

583. The **Aspen,** the smallest of the common Poplars, is rarely over fifty feet high, with a slender trunk (about 1 ft diameter) The bark remains smooth and light-coloured for many years, the leaves are rounded and not pointed The buds and flowers resemble those of Black Poplar, but the flowering buds are more distinct from the ordinary buds, being larger and less pointed, the bracts bear numerous long hairs on their edges, the stamens are fewer (about ten), the stigmas are red, not yellow

584. The **White Poplar** resembles the Aspen in many respects, but is easily distinguished by (1) the white down on its leaves (lower side) and young twigs, (2) the dry and hairy buds, (3) the frequently lobed leaves, (4) the less marked flattening of the leaf-stalk, (5) the slight hairiness of the bracts, (6) the four slender yellow stigmas It grows very quickly and may become a hundred feet high in forty years, with a massive trunk The White Poplar, like the Black, has a "pyramidal" variety

585. There are many different **Willows**, including varieties and hybrids, in Britain, but the commoner kinds are fairly easy to identify, and there are many points on which most of our Willows agree pretty closely The leaves are alternate, with stipules, and usually have prominent cushions which run down the stem for some distance The buds, which are generally pressed against the stem, may either produce long shoots bearing leaves, or short shoots which end each in a catkin, the short shoot sometimes bears a few leaves below the catkin (*e g* Crack Willow) Each bud shows on the outside only one large rolled-up scale, sometimes there are two small buds inside this scale, one on each side of the ordinary bud.

The catkin-bracts have silky hairs on the outer surface, and each flower has a green or yellow nectary, or two nectaries, at the base of the stamens or pistil on the side nearest the axis of the catkin The male flower has few stamens (two to five), the number (though not constant) serving to distinguish some of the species, the anthers are yellow, the filaments long The female flower has a pear-shaped ovary, generally carried on a stalk; the tapering upper end runs into a style with two stigmas which are sometimes branched, and the ovary has the same structure as in Poplars Bees visit the flowers for honey and pollen The capsule opens by two valves, as in Poplars, and the seeds have a tuft of hairs

Willows may be roughly divided according to the presence or absence of long slender quickly-growing shoots (osiers) which often grow about nine feet long in a single season, or according to the breadth or narrowness of the leaves

586. Among narrow-leaved Osier Willows a typical example is the **Crack Willow** (*Salix fragilis*), the yellowish osier-twigs of which can easily be broken off at the base, leaving a clean scar It is often seen in the "pollard" form (as are various other Willows as well as Poplars), owing to repeated cutting of the osier-twigs. The long (3 to 6 ins) leaf tapers to an oblique tip, and has both sides smooth, at the top of the stalk, just below the blade, there are usually small glands (compare leaf of Cherry). The stipules, which soon fall off, are half heart-shaped. In spring the end bud grows into a long shoot, while of the side buds (more pointed, closely applied to stem) some grow into ordinary shoots and others into short shoots, which bear first a few small leaves and end in a catkin There are two nectaries; two stamens, two stigmas, each slightly forked; capsule stalked.

587 Four other narrow-leaved Willows may be mentioned Of these (3) and (4) differ from the Crack Willow in having no foliage-leaves on the flowering dwarf shoots (1) **Almond-leaved** or **French Willow** (*S triandra*) resembles Crack Willow in most respects, but the leaf-stalk has no glands, the bracts are nearly hairless, and the male flower has three stamens (2) **White Willow** (*S alba*) has leaves 2 to 4 ins long, silky on both sides, stipules narrow and tapering, one nectary, two stamens, capsule-stalk very short (3) **Common Osier** (*S viminalis*) has very long leaves (4 to 10 ins), silky below, with wavy edge and narrow stipules, one nectary, capsule hairy (4) **Purple Osier** (*S purpurea*) is a small shrub (5 to 10 ft), with short stalked leaves, stipules small or absent, catkin-scales dark purple above, two stamens with their filaments joined (sometimes right to the top, so that there seems to be a single stamen with a double anther), anthers purple.

588. Among the broad-leaved Willows the **Goat Willow** or **Common Sallow** (*S caprea*) is a small tree, often about thirty feet high It has no long osier-shoots, the spreading main branches bear knotted twigs, useless for basket-making The leaves vary greatly in form, but are generally more or less oval and pointed, sometimes with a long bent or twisted tip; the leaf is wrinkled, the margin wavy, the upper side smooth but the lower side usually downy The stipules are half kidney-shaped The catkins open in March or April, the male catkin is short (about 1 in) and stout, but the female lengthens to about three inches The scales (bracts) are hairy, with black tips, the fruits open in May or June

589. Allied to Goat Willow, and perhaps only varieties of it, are the **Round-eared Willow** (*S aurita*) and the **Grey Sallow** (*S cinerea*, sometimes called *the* Sallow) The former is a small shrub with straggling branches, short (up to 2 ins) wrinkled leaves, kidney-shaped stipules, short catkins (about ½ in), the latter is a larger plant and has its twigs covered with a grey felt of short hairs

The **Bay-leaved Willow** (*S pentandra*) is a small tree with thick smooth shining fragrant leaves, fairly broad and pointed, the male flower has usually five stamens, but sometimes more The **Creeping Willows** are small dwarfed plants, divided into several species The commonest (*S repens*) grows abundantly on commons and heaths and has small oblong leaves, of the others, *S herbacea* (the smallest British shrub) grows on the higher hills in Britain, except in the south of England, *S reticulata* only on Scottish hills, both having short creeping stems (sometimes underground) and small (¼ to ½ in) rounded leaves

590. Hazel (*Corylus avellana*) is a small tree, rarely over 15 ft. high There is usually no main trunk, but several branches starting at the base of the tree From the base of the shoot arise numerous erect quickly-growing branches ("stool-shoots"), and similar branches ("suckers") are often given off by the root, the stool-shoots and suckers differ from the ordinary branches in having the leaves arranged in three rows instead of two. The bark remains smooth for many years, and has narrow transverse lenticels, in the older parts it becomes rough and scaly

The leaves are stalked and simple, the blade varies in form and amount of lobing, but has irregular pointed teeth on the edge, a pointed tip, a rough surface, and is usually larger on one side of the midrib than on the other, especially at the base. Are the leaves more lopsided on the two-rowed or on the three-rowed shoots? Is the larger half of the blade that nearest, or farthest from, the free end of the twig? Examine the lopsided leaves of Elm, Lime, Begonia, and try to find out the advantages of this kind of leaf to the plant

The twigs of the current year are hairy and have a zigzag appearance, the leaves (and buds) coming off singly at each bend The buds are egg-shaped but rather flat, and are covered with brown scales, within these come pairs of silky stipules without leaf-blades, then stipules with young blades between them, each young leaf being folded along the midrib

The uppermost bud on each twig grows out and forms a long shoot, but in summer the end of the shoot dries up, then the place of the lost end bud is taken by the uppermost side bud Most of the side buds, however, grow into dwarf shoots, which may either bear a few leaves or may produce a male or a female inflorescence

The "male bud" differs from the ordinary buds and the female buds in the fact that it grows at once, in the year it is formed, and produces first a few buds (which next year will become ordinary shoots or else female catkins) and then ends in from two to five male catkins The cylindrical male catkins, therefore, are visible in late summer, and by February (sometimes after a few fine days in January or even December) they open.

The drooping male catkin (Fig 153) has numerous concave green scales, each bearing on its downward face (its true upper face) two small scales and a number of stamens (Fig 154), each stamen has a short filament ending in a one-lobed anther (a half-anther) There are usually eight of these half-anthers, and (in some cases at least) their filaments are joined in pairs at the base, so that in reality there are only four stamens

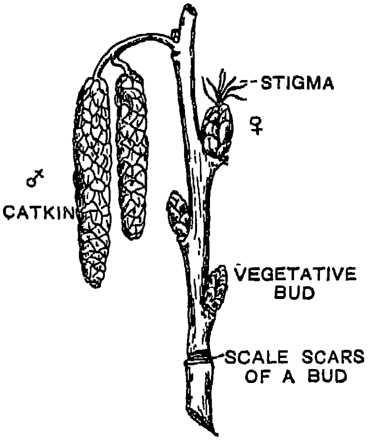

Fig 153 —Male and Female Inflorescences of the Hazel

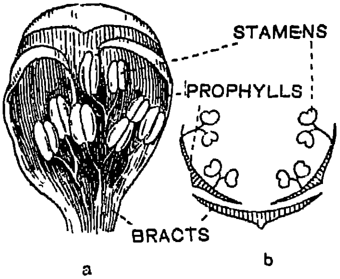

Fig 154 —Hazel
A, Male Flower, B, Diagram of same

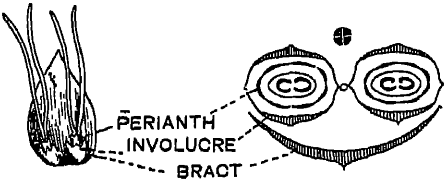

Fig 155 —Two Female Flowers of Hazel in Axil of a Bract, each with two long Stigmas, and Diagram of same

When the female bud opens, a tuft of about twenty scarlet stigmas projects from the top Carefully dissect the bud and note the brown outer scales, then several pairs of stipules, then a few small leaves, and finally about five bracts each with two female flowers (Fig 155) The flower consists of an ovary surrounded by a double cup at the base and bearing on top two long red styles, but the lower parts are very small at the time pollination occurs. Only a few flowers in each catkin develop into nuts, the ovary has two chambers, each with an ovule, but the nut has only one seed The cup becomes leafy and very conspicuous as the nut ripens What changes in colour, texture, taste, and size does the nut undergo while ripening? When are the nuts ripe? Note the embryo which fills the nut and has two large cotyledons containing starch and oil Sow ripe nuts, first soaking them in water · do the cotyledons remain below ground or come above it?

591. Alder (*Alnus glutinosa*) grows chiefly in moist places, beside streams and pools, in marshes and bogs, but will thrive in drier places which are sheltered or in which the air is moist enough. It is generally a small tree, but may reach a height of sixty feet, the trunk, however, rarely exceeds a foot in diameter.

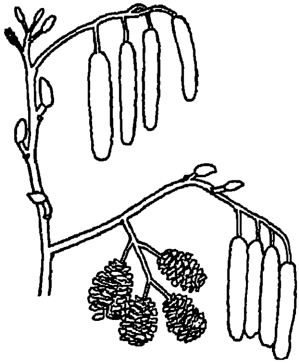

Fig 156.—Alder

Twig with male catkins, young female catkins (above), fruiting catkins (below), and resting buds

The Alder is rather like the Hazel in general mode of growth, being often shrubby owing to the production of numerous stool-shoots, but the roots rarely produce suckers. On the older parts of the shoot the bark is black and scaly, on younger parts it is brown, with very distinct lenticels

The young leaves have stipules which soon fall off; the blade is broad and usually notched at the end, and except at the base its edge is doubly toothed, the teeth being short The large egg-shaped brown resting buds are peculiar in that each is on a stalk The young leaves are pleated (Fig 36, *plicate*), and both they and the twigs are sticky at first The buds are covered by two or three scales, which are rather difficult to separate and have a waxy coating

The catkins open in February before the leaves appear Both kinds of catkins can be seen in the previous autumn, and in winter they are very conspicuous on the bare twigs. Needless to say, the ordinary resting buds of Alder contain only foliage-leaves

The male catkins are cylindrical and are nearer the end of the shoot than the shorter female ones Each scale is thickened at the outer edge and bears, on its (true) upper surface, three flowers, each with a green four-lobed "calyx" and four stamens In the female catkin, which usually turns upwards and does not droop like the open male catkin, each scale bears two flowers resembling those of Hazel in structure but having no "calyx"

After fertilisation the ovary grows into a dry akene; the scales become stalked, hard, and woody, giving the old female catkin the appearance of a Pine cone The cone ripens in autumn, but remains closed until the following spring, when the scales become separated and the akenes (which have a spongy coat) may be blown away by the wind or may fall into water and be carried by it

592. Birch (*Betula alba*) is easily recognised by its thin main stem (sometimes forty feet high), which runs up to the top of the tree and is rarely over a foot in diameter, its slender twigs, which often droop at the ends, and the light foliage, which together give the tree its graceful appearance, and its smooth thin white papery bark with long, dark transverse lenticels

There are two varieties in Britain, "White" Birch and "Common" Birch, they are connected by variations and hybrids, but the "Common" Birch is distinguished by its branches being more spreading and rarely drooping at the ends, its twigs *not* being covered with hairs, its bark being, at the base of the trunk, rough, dark, and furrowed, and by its hairless and longer-tipped leaves with the blade placed horizontally The young bark is brown in both cases, becoming white later on

The leaves are arranged all round the stem, but sometimes tend to form two rows, the stalk is thin, the blade variable in outline (heart-shaped, diamond-shaped, etc.), doubly toothed, with pointed tip. Since the leaves are relatively small, well spaced on the slender twigs, long-stalked, and hang vertically on the drooping twigs, they cast little shade. Hence the Birch catches but little light, as compared with trees which spread out their leaves and form a mosaic. It is, in fact, the most exacting tree in its demand for light, and conversely it grows worse in shaded places than any other tree in Britain.

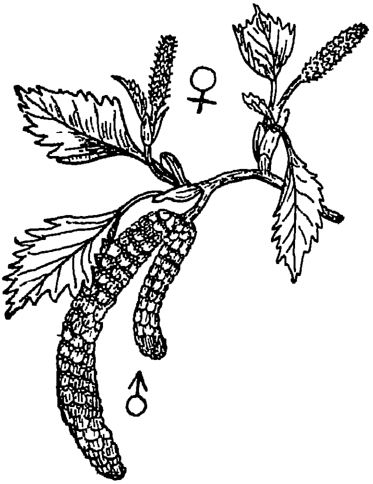

Fig. 157.—Birch. Twig showing male and female catkins.

Between an extreme light-demanding tree like the Birch and an extreme shade-enduring tree like the Beech we get various intermediate trees. The buds are small, pointed, dark brown, some produce long shoots, others dwarf shoots. Each year the end of the long shoot dies and its growth is continued by the uppermost side bud.

The catkins open along with the leaves in March or April (Fig. 157). Both kinds are cylindrical, the female catkins are at first erect and more slender than the male catkins, but later (in fruit) become much larger. The male catkins are visible during autumn and winter (as in Hazel) at the ends of twigs in twos or threes. In spring the male catkin lengthens and droops, the scales separate, and the pollen is blown out. Each scale (bract) bears (on its true upper surface) several small scales and three groups of stamens, each group consisting of two stamens each split into half-stamens (Fig. 158, c).

Each female catkin is produced inside a resting bud; in spring this bud grows out, produces a few foliage-leaves, and ends in a slender catkin (Fig. 157). Each scale bears on its upper side two small scales (*bracteoles*, Fig. 158, A) and three flowers Each flower consists of a pistil (like that of Hazel in structure), without any cup The akene is flat and produced at each side into a thin wing In autumn the scales fall off and the light-winged fruits are dispersed by the wind

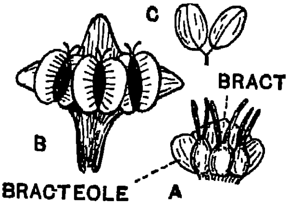

Fig 158 —Birch

A, Female flowers in axil of bract, B, Fruiting scale, with three samaras, C, stamen from male flower

Examine twigs in autumn, noting the ripe female catkins of this year, and the male catkins and the buds for next year, rub, or pick to bits, a fruiting catkin and note the scales and the winged akenes (Fig 158, B). The seedling has two small green cotyledons, carried up, the first foliage-leaves are less toothed and more hairy than the later ones

593. Oak (*Quercus robur*), the largest of British trees, sometimes 150 feet high, with massive trunk, is easily recognised at all times of year Even when without its wavy-lobed leaves or its acorns, it differs from other trees in its gnarled and contorted main branches and in having its buds crowded round the ends of the twigs (see Art 320)

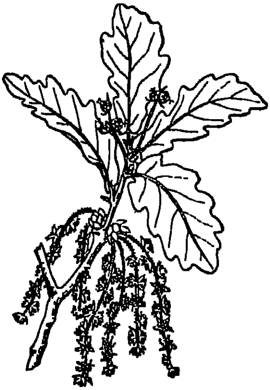

Fig 159 —The Stalked Oak, with Flowers.

In the commoner variety of the Common Oak (Stalked Oak) each group of acorns is carried on a stalk, in the other variety (Sessile Oak) the acorn-group has no stalk The Oak leaf has small stipules which soon fall off In Stalked Oak there is no leaf-stalk, or a very short one, in Sessile Oak the leaf-stalk is long, in Sessile Oak the blade is firmer, more tapering at the base, and has hairs on its lower side.

The flowers appear with the leaves in April or May. The male catkin bears numerous flowers scattered singly or in groups on the axis, each flower (Fig 160, c) has a deeply 5- to 7-lobed "calyx" and from 5 to 12 stamens The female catkin has fewer flowers (1 to 5); each flower has a shallow cup covered with triangular overlapping scales, and inside this, the future acorn-cup, there is a 6-toothed "calyx" (Fig. 160, D, *perianth*) inserted above the small ovary, which has a style with three stigmas. The ovary has three chambers, the ovules (two in each chamber) are not even developed until after pollination. As a rule only one seed is present in the ripe acorn; still one often finds

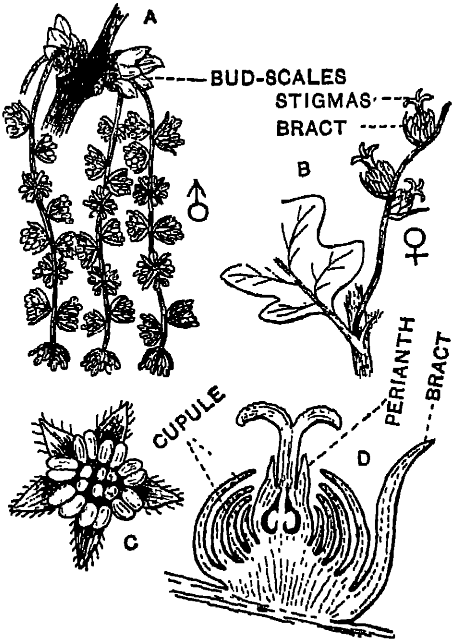

Fig 160 —Oak

A, Male, B, Female Inflorescences, C, Male flower, D, Female flower in section three or more, especially in looking for seedlings The seed is filled up by the embryo, whose thick cotyledons contain starch, together with tannin, oil, sugar, etc See Art 160

[**594** A few notes may be added on some introduced Oaks commonly grown in Britain, which differ from the Common Oak in various details. (1) **Turkey Oak** has the leaf-lobes long and pointed, and the acorn (not ripened until the year after the flowers open) has its cup covered with long outgrowths, this Oak is also called the **Moss-cupped Oak.** (2) **Evergreen** or **Holm Oak**, with evergreen leathery leaves, entire or with spiny margin, glossy above, greyish below. (3) **Cork Oak,** like Evergreen Oak, but with thick corky bark]

595. Beech (*Fagus sylvatica*), which is so easily distinguished by its smooth grey bark, its ovate leaves, fringed with hairs when young, its long brown tapering buds, and its three-sided nuts in pairs within a four-lobed spiny cup, is one of our largest trees, often over a hundred feet high It frequently has very characteristic rounded ridges or buttresses at the base of the trunk, which run out to the shallow roots.

The leaves are arranged in two rows, and on horizontal or inclined branches their insertion is nearer the lower than the upper side of the branches, by twisting of the stalks the blades all present their upper faces to the light The blades vary in shape, but are usually symmetrical and taper above and below On young trees the dead leaves often remain attached during the winter

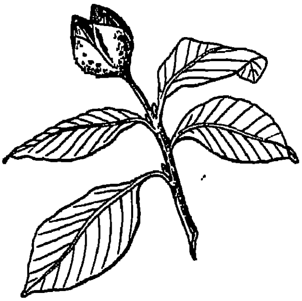

Fig 161 —The Beech, with a Fruit.

Besides the ordinary long branches there are dwarf shoots which grow very slowly and bear few leaves each year, inspection of the "girdle-scars" (close-set scars of bud-scales of former end buds) will often show that a dwarf shoot has grown less in length in about twenty years than a long shoot in about a month The dwarf shoots do not branch, and bear crowded leaf-scars and annual girdle-scars. Sometimes a dwarf shoot grows out, after several years, to form a long shoot, owing to the fall of a branch above it or some other cause which gives it plenty of light

Carefully examine a branch of Beech and note how beautifully the long and short shoots are arranged and mixed and how the sizes of the leaf-blades are varied, so that the leaves form a close mosaic and catch a large amount of light Hold the branch against the light, and you will understand one reason why the Beech casts such a dense shade and why so few plants can grow under Beeches, when growing in a wood the main trunk runs up nearly to the thick crown of the tree, but in the open the stem branches low down into several strong cylindrical trunks, while the leafy "crown" comes nearly to the ground From these observations you will understand why Beech is called a "shade-enduring" tree (more so than any other tree in Britain), while Birch is called a "light-demanding" tree

The long zigzag twigs have the buds standing off at an angle of about 60°, the end-bud may either persist or be replaced by the uppermost side-bud. Each bud stands at the side (upper side) of the leaf-scar (small, oval, with three bundle-scars) In autumn the tips of the shoots cease to form leaves, but keep on forming stipules which act as bud-scales The scales are pale brown, arranged in four rows, the outermost scales are broad, short, pointed, but those further in are longer, narrower, and more delicate in texture. The first seven or eight pairs of scales have no leaves, but the innermost pairs have a small leaf-blade between them, then come the pleated foliage-leaves with their stipules densely covered with silky hairs.

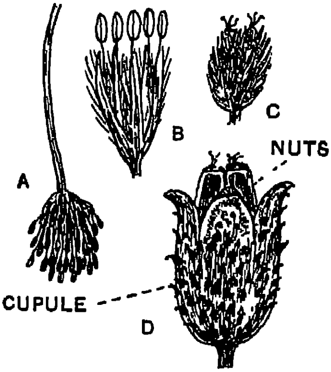

Fig 162 —Beech

A, Male inflorescence, B, Male flower, C, Female inflorescence, D, Cupule with nuts

As a rule the highest buds on a twig grow into long shoots, those lower down into dwarf shoots, and the lowest ones remain dormant, the dormant buds do not, however, remain alive and capable of growth for nearly so many years in Beech (rarely 20 years) as in other trees, hence one does not see young shoots growing from the old trunks of Beeches, like those on Oaks, Elms, etc

The flowers, which come out with the leaves in spring, are in clusters at the ends of slender branches which arise singly in the axils of the leaves, the female clusters being higher up on the twig than the male The male branch has a long hanging stalk, that of the female branch is shorter, thicker, and erect The numerous male flowers (Fig 162, B) have each a bell-shaped "calyx" with five to seven teeth, covered with hairs, and about ten stamens The female branch has only two flowers (Fig 162, C) surrounded by a four-lobed cup covered with soft outgrowths, each flower has a "calyx" with four to eight teeth above the three-chambered ovary (two ovules in each chamber), and the style has three stigmas

After fertilisation the cup becomes woody and its outgrowths stiff or even spiny, about October the four lobes spread out and let the nuts escape (Fig 162, D) The nut is filled by the embryo, which has two folded cotyledons On germination the cotyledons are carried up and spread out as broad green leaves For several years the young plant grows very slowly; each year the end of the stem bends over so that the leaves (set in two rows) shall not shade each other, then the upward growth for the next year is carried on by a bud on the top of the bend

The **Copper Beech** is a variety of Common Beech in which the epidermis of the leaf contains a red pigment (dissolved in the sap of the epidermal cells), the mesophyll consists of green tissue, as in the ordinary Beech

596. The Hornbeam is usually much smaller than the Beech, and is most commonly seen in hedges, but its leaves and flowers resemble those of the Beech, though the former are not shiny, and are doubly serrated The male flowers are in dense cylindrical catkins, and the female flowers in loose catkins The fruit has one seed, and is enclosed in a lobed bract (Fig. 164), which enables it to be carried by the wind.

[**597. The Sweet** or **Spanish Chestnut** has long, oval, toothed leaves, which remain on the tree till late autumn, when they assume a rich golden colour. The flowers are produced in long spikes during July, the male flowers being situated on the upper parts of the spike, and the female flowers near the base. The former soon wither and fall, while the latter develop into tiny husks, lined by silky hairs, and each containing from two to five pointed nuts, some of which do not fully develop. The fruit is ripe in September, and falls in October, when the cupule splits and exposes the nuts. The seeds ripen in Britain only in warm seasons or favourable localities.]

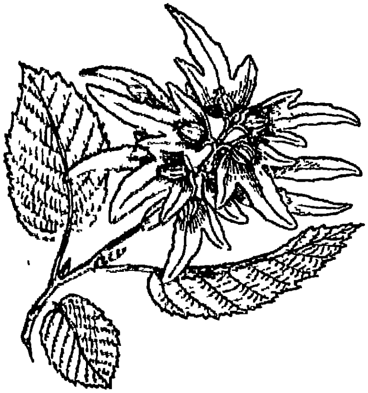
Fig. 163. The Hornbeam, with Cluster of Fruits.

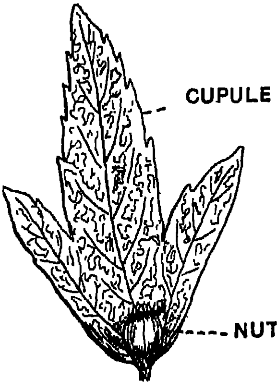

Fig 164.—Fruit of Hornbeam

598. Elm (Figs. 165, 166).—There are two kinds of Elm in Britain, the **Common** or **English** Elm (*Ulmus campestris*) and the **Wych, Scots,** or **Mountain Elm** (*Ulmus montana*); roughly speaking, most Elms growing south of the Trent belong to the former species, while most Elms north of the Trent belong to the latter.

In both Elms the bark is rough and shoots are often produced from the lower part of the trunk. Both grow into tall trees (up to about 120 feet), and have short-stalked simple entire doubly-toothed leaves arranged alternately in two side-rows on the stem. The blade is roughly heart-shaped in outline, but one half (that nearest the tip of the twig, or that farthest from it?) comes off the leaf-stalk lower down than the other half and bulges out, so that the blade is lopsided.

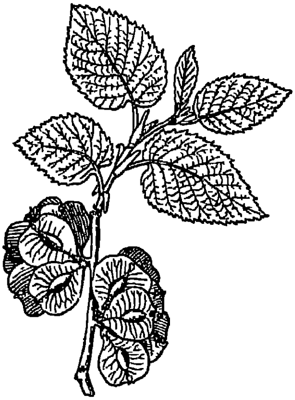

Fig 105.—The Elm, with Clusters of Fruits

The advantage of this lopsidedness is easy to observe if you hold a leaf-bearing twig up to the light and notice how the larger half of each blade tends to fill up what would be a space (if the leaf were symmetrical) between the leaf, the stem, and the leaf above. This peculiarity of the leaf-blade, enabling the leaves on a twig to catch more light without too much overlapping of each other, is a simple method of producing a leaf-mosaic; it is more pronounced in the Wych Elm (leaf 3 to 6 ins. long, up to 3 ins. across broadest part, taper-pointed) than in Common Elm (leaf about 2 ins. long, not so pointed).

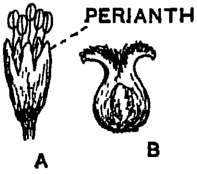

Fig 106.—Elm
A, Flower; B, Pistil

In Wych Elm the crown is broader and the main branches more spreading than in Common Elm; the latter has its bark more deeply furrowed. There are two kinds of buds; the higher ones are pointed and grow into leafy shoots (either long shoots or dwarf shoots), while the globular lower buds produce clusters of flowers. The buds have much the same structure as in Hazel; the young leaves have stipules which soon fall off; the branches, like the leaves, are in two side-rows; the true end-bud dies off each year, and the uppermost side-bud replaces it.

The flower-buds open first, in March or April, each producing a dense tuft of small brownish-green flowers; each flower has a bell-shaped "calyx" with four to eight lobes, a stamen opposite each lobe, and a two-chambered ovary with two long red stigmas (Fig 166) At first the stigmas project beyond the stamens and are receptive, but after a time the filaments lengthen and carry out the anthers, which then open The pollen is carried by the wind, it is obvious that self-pollination is prevented during the female stage of the flower, but it may occur when the anthers of the flower open if cross-pollination has failed

The ovary becomes an akene, with a thin wing around the seed-containing part, the fruits (oval, notched above) are at first green, but become brown and ripe by May In Wych Elm the seed is at the centre of the fruit (about 1 in long), in the smaller fruit of Common Elm (about ½ in long) it is above the centre The seeds of Common Elm are said never to germinate in this country, but this is largely atoned for by the fact that this species of Elm sends up numerous suckers from its roots, so that one often sees a long stretch of hedge on each side of an old Elm, or a thicket of young Elms around the parent tree. The Common Elm is not regarded as a native British tree, but as having been introduced within historic times The Wych Elm, regarded as native, does not produce suckers, as a rule, unless the tree is cut down, its winged akenes (samaras) are well adapted for wind-dispersal, and in germination the green cotyledons are carried into the air

Common Elm differs from Wych Elm chiefly in having smaller leaves, flowers, and samaras, fewer "calyx"-lobes and stamens; in the non-germination of its seeds in Britain, and its production of suckers in large numbers from the roots; in the direction of growth of its main branches and the shape of the crown.

599. Sycamore Maple or **False Plane** (*Acer pseudo-platanus*), usually called simply Sycamore (though this name was originally given to a wild Fig, *Ficus sycomorus*, growing in the East), is not a native of Britain, though so common here; its home is in central Europe and western Asia The Sycamore is really a species of Maple, the only native British species of *Acer* is the **Field** or **Hedge Maple** (*A campestris*), but two other species are commonly grown—**Norway Maple** (*A. platanoides*) and **Ash-leaved Maple** (*A negundo*) They all have the leaves in crossed pairs (therefore in four rows, *decussate* arrangement) and a fruit which splits into two (sometimes three) winged akenes (samaras)

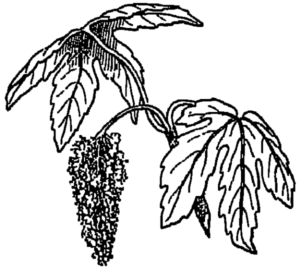

Fig 167 —The Sycamore, with Flowers.

The **Sycamore Maple** (Fig 167) is a fairly tall tree (up to 60 ft), the bark long remains smooth, but eventually becomes rough and scaly Each leaf has a stalk whose broad base extends about half round the stem, the blade (4 to 8 ins broad) has five pointed toothed lobes and is shiny and dark-green above, dull and light-green below The main veins spread out from the top of the stalk, one running to each lobe and giving off side-veins, in the young leaf the veins are fringed below with hairs, but in the old leaf the hairs are confined to tufts at the points where the secondary veins join the five main veins

On a horizontal branch the leaves are arranged so that the blades may get as much light as possible, the leaf stalks vary in length, and those of the upper and lower rows of leaves become twisted, while the blades vary in size, in amount of lobing and sizes of the lobes, so as to produce an effective leaf-mosaic On a more or less horizontal branch the buds (Art 318) on the upper and lower sides either remain dormant or grow into very short shoots, so that on an old branch of this kind the long twigs are confined to the flanks, but on more erect branches there are strong twigs on all sides, especially on the side farthest from the middle of the tree How may these facts be explained?

A flowering shoot (how can you tell in winter which buds contain an inflorescence?) bears one or two pairs of leaves and ends in a long hanging bunch of stalked green flowers At the base of the inflorescence branches bearing each about three flowers arise from the axis, but higher up it gives off single flowers Note the five sepals, the five petals (narrower than the sepals), the stamens (8 to 12) inserted on a yellow ring-like cushion (nectary), the hairy flattened ovary (two chambers each with two ovules), and the short style with two curved stigmas As a rule the central flower in each group has a fully developed pistil, and eight stamens with short filaments, but the anthers (though containing pollen) do not open, so that the flower is practically female The other flowers are male, having eight to twelve stamens with long filaments, and a small sterile pistil. Sometimes a whole inflorescence consists of these male flowers, in all cases the male flowers appear to mature before the female flowers The flowers are visited by insects, chiefly bees and flies

The fruit has two spreading and diverging wings, one produced from the outside of each chamber or half-fruit Each chamber contains a large rounded seed (Art 161) Eventually the whole inflorescence falls off, leaving a saddle-like scar on the stem

600 The **Field Maple** is a small tree (rarely over 30 ft high) with spreading branches, the bark has numerous fine furrows dividing it into scales The leaves are smaller than those of Sycamore, with blunt lobes and both surfaces nearly alike The buds are small and pressed against the stem The inflorescence is erect, and its branches are arranged so as to bring the flowers nearly to the same level, the flowers are male, female, or perfect The wings of the fruits are horizontal or even bent downwards, and the seed-chamber is flattened

[**601.** The **Norway Maple** is rather like the Sycamore in size and general appearance, but the leaves are smoother and the buds are red (sometimes they are red in Sycamore), the inflorescence is like that of the Field Maple but with more flowers, and the fruit has horizontal wings but is larger than in Field Maple]

[**602.** The **Ash-leaved Maple** or "Box Elder" is a North American tree with compound leaves, there are from three to five leaflets, the lower ones in pairs, the odd leaflet often three-lobed The twigs droop, and are green when young, the bud has no proper scales, but is protected by the base of the leaf-stalk in whose axil it stands The flowers have no petals and no nectary, they are completely unisexual, the male and female flowers being on different trees The male flowers are in hanging tufts, each flower on a long stalk, the calyx is bell-shaped, the stamens (3 to 5) have long filaments The female flowers are in loosely branched racemes, the sepals are small, and the pistil, with its long stigmas, projects well beyond them The flowers open, with the leaves, in April, and are wind-pollinated, the brown fruits (ripe in August) have the two wings nearly parallel or converging at the top The leaves are often variegated with white blotches, or may be entirely white in some cases, but the tree always has plenty of green leaves besides the variegated ones]

[**603. Horse Chestnut** (*Aesculus hippocastanum*) is a large tree (about 60 ft), with erect trunk and pyramidal head, it is a native of Asia and North America and was introduced into Britain about 1630 The name is probably derived from the resemblance of its seeds (too bitter for human food, though eaten by various animals) to the edible fruits of Sweet Chestnut, "horse" being a contemptuous prefix meaning coarse, as in Horse Radish, or as "dog" in Dog Violet, Dog Daisy, etc

The twigs are thick, the buds (Art 319) large, brown, and sticky; the branches ascend at first, then bend downwards and often curve up again at the ends The bark is smooth for many years, but later becomes grooved and scaly. The leaves are in crossed pairs As in Sycamore, the leaves differ according to their position on the branches, the lower ones having larger blades and larger stalks, but the mosaic is made more perfect by the fact that the leaves are compound, so that the individual leaflets can vary in shape and thus catch the light more fully.

The leaf-stalk has a broad base and is also broadened at the top where the leaflets (5 to 9, typically 7) come off The leaflets themselves have no stalks; each has a sharp tip, just below which the leaflet is broadest, and a toothed edge On a horizontal branch the lower buds either remain dormant or grow into small and short-lived twigs When the inflorescence eventually falls off from the end of a flowering twig, a saddle-shaped scar is left, and the onward growth is usually continued by one of the uppermost side buds

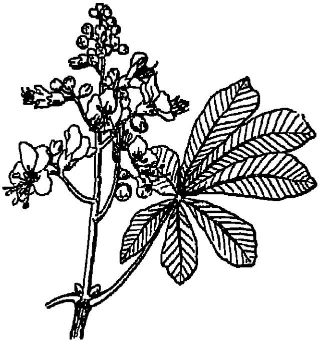

Fig 168.—Flowering Branch of Horse Chestnut.

The flowering branches (Fig. 168), whose buds are much larger than the ordinary buds, resemble those of Sycamore in general structure, but are erect; they open in April or May, as a rule, sometimes not until June. The thick erect axis bears clusters of flowers below, single flowers at the top Each cluster contains (1) male flowers, with stamens but no pistil, (2) complete flowers, of which some are really female, since the stamens fall off before the anthers open, (3) flower-buds, which do not open but wither and fall off

Each flower is stalked, stands out horizontally, and is irregular (*zygomorphic*), there are five united green sepals forming a bell-shaped calyx, four free petals (an upper pair and a lower pair, sometimes with a fifth odd petal below) Each petal is white, with a yellow blotch (larger in the two upper petals) which later turns red, and jagged edges Within the petals there is a ring-like nectary, thickest at the upper side of the flower, and within this the stamens (usually seven) are inserted Each stamen has a long filament which turns up at the end and bears a red anther The pistil has a three-chambered ovary (two ovules in each chamber) and a long pointed style bearing stigmatic hairs.

The flowers are visited by insects, especially bees In a perfect flower the style is ready to receive pollen before the anthers open When a bee visits a newly opened flower the style, which projects forwards and upwards, touches the bee's abdomen, while the unripe stamens are bent down Later the stamens ripen and turn forwards and upwards, so that the anthers are brought into the position formerly occupied by the style Cross-pollination is further aided by the fact that the male flowers in an inflorescence are the first to open, also by the presence of the "female" flowers, *i e* those whose anthers fall off without having opened

The ovary grows into a brown globular spiny fruit (a *capsule*, though differing from most capsules in having a rather fleshy wall), which opens (about October) by three valves and usually contains two seeds See Art 166.]

[**604.** Some varieties of Horse Chestnut have "double" flowers, with structures intermediate between petals and stamens. The **Buckeye Horse Chestnut** (*A pavia* or *Pavia rubra*) is a small tree (up to 20 ft), with five *stalked* leaflets to each leaf, dull (not sticky) buds, small flowers, and smooth fruits The **Red Horse Chestnut** (*A rubicunda*) has very dark-green leaflets, dark-red flowers, and spiny capsules, but the leaflets are (as in the Buckeye) spindle-like in outline, though not stalked]

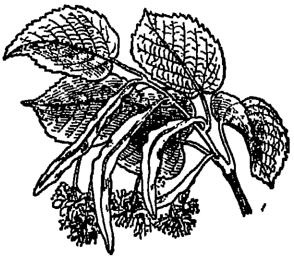
Fig 169.—The Lime—Leaves and Flowers.

[**605. The Lime.**—This tree (Fig 169) grows wild in a few of the southern counties, and is consequently sometimes supposed to be a native; but this is doubtful, since the seeds do not germinate in uncultivated soil It does not flourish well in the north The leaves are heart-shaped, with serrated edges

Its flowers, which bloom in June and July, have five sepals, five petals, many stamens, and a five-celled ovary with two ovules in each They are of a greenish yellow colour, and have a long leaf-like bract attached to the axis of the inflorescence (a cyme) They are also very fragrant, and produce abundance of nectar, and are consequently very attractive to insects The fruits are nuts, and the persistent bract forms a wing which aids in their dispersal by wind]

[**606. Common Lilac** (*Syringa vulgaris*), a native of Persia and Central Europe (introduced into Britain about 1600), forms a shrub or small tree (up to 20 feet), which grows rapidly (as much as a yard per year for the first three or four years), but does not last very long—about 20 years in rich soils, but 40 or 50 in dry poor soils (why this difference in duration?) , it is well known for its handsome appearance when in leaf and its abundant and beautiful flowers. It sends up suckers profusely in all directions, why do gardeners clear these away as they appear, when a fine tree is desired?

The leaf has a long stalk, the blade, usually heart-shaped but rather variable in outline, is thin and has its surface smooth and its edge entire. The leaves are in crossed pairs The buds are large and green, the bud-scales are smooth and green, in crossed pairs As a rule the end-bud has either died off or produced an inflorescence, so that the end of a twig usually has two buds side by side. The buds are somewhat sunk in the base of the leaf-stalk in whose axil it stands, and each has four or five pairs of hard scales, then about ten pairs of young leaves which just touch each other at the edges, so that the bud is a very easy one to dissect. Some of the buds contain only leaves, others (larger) both leaves and an inflorescence.

The flowers (blue, purple, red, or white, in different varieties) are in large loose clusters, the main axis bearing groups of stalked flowers on its branches. The calyx is short and four-lobed, the corolla has the same general shape as that of a Primrose, consisting of a long trumpet-like tube and four horizontal lobes. There are two stamens inserted by short filaments on the inner surface of the corolla-tube. The ovary is two-chambered, the style long and ending in two small stigmas. Besides being fragrant, the flowers have honey, produced at the bottom of the tube, they are visited by bees and butterflies. The capsule opens by two valves, the calyx is persistent.]

[**607.** Besides the Common Lilac several other species are grown in Britain, e.g. **Persian Lilac** (*S. persica*), introduced in 1840, with purple flowers (in some varieties white), small lance-shaped leaves (in some varieties lobed deeply), a small shrub (4 to 6 feet), **Josika's Lilac** (*S. josikaea*), about as large as Common Lilac, but with leaves broadly lance-shaped, wrinkled, short-stalked, and white below, introduced in 1835, flowers purple, but the corolla-lobes not spread out, and the **Rouen Lilac** (*S. rothomagensis*), a hybrid between Common and Persian with intermediate characters, a shrub about 7 feet high.

All the Lilacs are propagated by the suckers, good seeds are not usually formed unless the suckers are mostly cut away and the bunches of flowers thinned out (why?). They can all be grafted on the Ash, which belongs to the same family (Oleaceae).]

608. Common Ash (*Fraxinus excelsior*) is a fairly tall tree, often 80 feet high, it is a native of Britain, but has generally been planted. It is easily distinguished by its stout grey twigs, usually turned up at the ends, its compound leaves in crossed pairs, and its stumpy black buds, also by its characteristic "keys". See Fig. 170.

Note that the base of each leaf runs down on the stem as a projecting cushion, so that the stem is flattened below each pair of leaves, this gives the twigs a knotted appearance when the leaves have fallen. The leaves have about five pairs of side-leaflets and an end-leaflet; the leaflets are stalkless, narrow, pointed, and slightly toothed.

The buds have 4 to 6 pairs of scales, of which only the outermost ones (2 to 4 scales) are visible on the outside, these outer scales are covered with black hairs When the bud opens, one generally sees transitions between the bud-scales and the foliage-leaves. The large end-buds grow into leafy shoots, but in April, before the leaves appear, clusters of flowers grow out from the side-buds

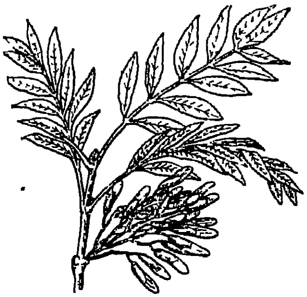

Fig 170 —The Ash, with Cluster of Fruits

The inflorescence shows the same branching as in Lilac; the main axis gives off branches which branch again, and the last branches end in flowers The flowers may be either male, female, or perfect, the three kinds may be present on the same tree or on separate trees, being grouped in various ways There are always two stamens in a male or perfect flower (filaments joined below in male flower), while the pistil is bottle-shaped and consists of a two-chambered ovary, tapering style, and two stigmas The flowers are mostly wind-pollinated, though sometimes visited by insects

The fruits are winged akenes (samaras), the long and often twisted wing is formed from the top of the ovary and shows at first the remains of style and stigmas on its tip Note the thickened basal part of the key, forming a cavity which contains the single long flat seed When the seed germinates, the whole key is carried up, the cotyledons remain inside it at first to absorb the food stored in the endosperm, then come out and form oval green leaves The first foliage-leaves are three-lobed, but not compound

[In the **Manna Ash** (*Fraxinus ornus*) of South Europe the flowers have sepals and petals, so that the Common Ash has evidently lost these parts through becoming wind-pollinated The Ash belongs to the same family (Oleaceae) as Lilac, Jasmine, Forsythia—commonly cultivated shrubs—Privet (in Britain), and the Olive]

609. Notes on Other Common Trees and Shrubs— The trees and shrubs already described in this chapter and under their Families in the preceding chapters are not mentioned in the following lists. Introduced (*i e* not native to Brit) trees and shrubs are placed in square brackets.

I Leaves in Opposite Pairs, Simple, with Entire or Serrate Margins.—The following are **deciduous**:—

Spindle Tree (*Euonymus europaeus*), 6-20 ft , 4-angled twigs, leaves lanceolate, greenish-white reg flrs in cymes, parts in 4's, red 4-lobed fruit with large orange seeds

Dogwood (*Cornus sanguinea*), 6-10 ft , twigs red, acute ovate leaves turning deep red in autumn, reg. cream-white flrs. in cymes, K (4) minute, C 4, A 4, G $\overline{(2)}$, black berry

Honeysuckle (*Lonicera periclymenum*), 10-20 ft , long-tubed zygom. flrs in heads, red berry [several cultd species, some with leaves joined by bases around stem]

Wayfaring Tree (*Viburnum lantana*), 6-20 ft , broad ovate leaves downy below, white reg flrs in flat cymes, berry red but finally black

[*Diervilla* (= *Weigelia*), 3-6 ft , acute ovate serrate leaves, large flrs with reg funnel-shaped C-tube, which changes colour after pollination, large stigma, large nectary at base of style, minute ovary]

[**Snowberry** (*Symphoricarpus*), 3-6 ft., ovate entire leaves, small globular flrs , white berries]

[*Leycesteria*, almost evergreen, trained against walls, 6-8 ft , leaves lanceolate entire, flrs. purplish-white in drooping racemes with large purplish fringed bracts (gen 6 to each whorl of flrs), K (5), C (5) with funnel-shaped tube and spreading lobes, A 5, G (5), large purple berry]

[**Mock Orange** (*Philadelphus*), white reg flrs , K (4-5), C 4-5, A ∞, G 4, capsule]

[*Deutzia*, 4-6 ft , twigs purplish and downy, white reg flrs., K (5-6), C 5-6, A 10-12, G (3)]

[*Hydrangea*, 3-6 ft , leaves serrate (sometimes lobed), reg flrs in large corymbs, K (5), C 5, A 10, G (2), outer flrs (or all) sterile with petaloid calyx.]

[*Catalpa*, 20-30 ft , large cordate leaves (sometimes in 3's), large white flrs in infl like that of Horse Chestnut, K (5) 2-lipped, C with bell-like tube and 4 lobes, A 5 (3 sterile, 2 fertile), G (2), capsule long.]

[*Buddleia*, 12-15 ft , twigs 4-angled and downy, leaves lanceolate downy below, flrs. small in stalked yellow-orange globular heads, K (4), C (4), A 4, G (2).]

[*Forsythia*, allied to Lilac and Jasmine, twigs 4-angled, leaves lanceolate, yellow drooping flrs in tufts appearing before leaves.]

The following are **evergreen** :—

Box (*Buxus*), 8-12 ft , twigs 4-angled, leaves oblong ½-1 in., flrs. green in small spikes (lower ♂, upper one ♀) ; ♂ flr. has P 4, A 4, and a central nectary (= sterile pistil); ♀ flr. has P ∞, G (3) with 3 style and 3 nectaries; capsule opens explosively by 6 slits and ejects the 6 seeds.

Privet (*Ligustrum*), 4-10 ft., leaves longer and not so persistent as in Box, twigs cylindrical, infl. as in Lilac, flrs. white, K (4), C (4), A 2, G (2), black berry.

[**Periwinkle** (*Vinca*), 2 species in Brit. (*minor* and *major*), but not natives, flowerless stems trailing and rooting, but flowering branches erect (note different arrangement of leaves), flrs. solitary, K (5), C (5) with long tube and flat limb, A 5, G (2), fruit = 2 follicles but rarely formed in Brit.]

[**Variegated Laurel** (*Aucuba japonica*), allied to Dogwood, 6-10 ft., very hardy and smoke-enduring, large serrate yellow-spotted leaves, brown-red flrs. ♂ and ♀ on separate plants, K (4), C 4, A 4, G (2), red 1-seeded berry.]

[**Laurustinus** (*Viburnum tinus*), allied to Wayfaring Tree, 8-10 ft., flrs. white (buds pinkish) in corymb, Dec.-Mar., all fertile.]

II. Leaves in Opposite Pairs, Simple, Lobed.—

Guelder Rose (*Viburnum opulus*), like Wayfaring Tree, but leaves deeply 3- or 5-lobed, petiole with glands below blade, outer flrs. of cyme large and sterile, berries red.

III. Leaves in Pairs, Compound, Pinnate.—

Elder (*Sambucus nigra*), 10-30 ft., twigs angular with conspicuous lenticels, side-leaflets in 2-4 pairs, white reg. flrs. in large flat cymes, K (5), C (5), A 5, G $(\overline{3})$.

[**Jasmine** (*Jasminum*), several species cultd., with varying number of leaflets, all twining or rambling plants, allied to Lilac, flrs. scented, yellow or white, with long narrow C-tube, fruit a 2-lobed berry but not often formed in Brit.]

[**Trumpet Flower** (*Bignonia capreolata*), climbing by leaflet-tendrils, leaflets gen. 2, oblong cordate; flrs. large, orange-brown, zygom., K (5), C (5) 2-lipped, A 2 + 2, G $\underline{(2)}$, capsule 2-valved, seeds with broad wing.]

[**Rooting Trumpet Flower** (*Tecoma radicans*), climbing by roots like Ivy; leaflets (gen. 7 or 9) ovate serrate, flr. as in *Bignonia*, but C-tube long, flrs. red.]

IV. Leaves Alternate, Simple, Entire, or Serrate. The following are **deciduous** —

Common Buckthorn (*Rhamnus catharticus*), 5-10 ft., with spiny branches, ovate serrate leaves (sometimes opp.), small greenish axillary unisexual flrs., parts in 4's, black berry; **Alder Buckthorn** (*R. frangula*), not spiny, leaves obovate entire, flrs. ☿, parts in 5's.

Bog Myrtle or **Sweet Gale** (*Myrica*), 2-3 ft.; leaves obovate or lanceolate, serrate at tip, flrs. in catkins before leaves.

Sea Buckthorn (*Hippophae*), 1-8 ft., on sandy shores, branches ending in a spine; leaves lanceolate, silvery with star-like hairs, flrs.

small, axillary, ♂ and ♀ on separate plants, ♂ flr. has P of 2 scales which cover the 4 sta. in wet weather and expand when the air is dry, ♀ flr. has 2-lobed tubular P which becomes fleshy around akene.

Mezereon (*Daphne mezereon*, much cultd., but perhaps native in S. England), 2-4 ft., leaves lanceolate, flrs. red (sometimes white) small, reg., before leaves, P (4) with tube and spreading lobes, A 4 + 4, $\underline{G}$ 1, berry red or yellow.

Barberry (*Berberis vulgaris*), 6-10 ft., often cultd., has long shoots with their leaves passing into 3-lobed spines and bearing in their axils short shoots which produce ordinary leaves and infls., leaves obovate serrate, flrs. in drooping racemes, yellow, P 12 in 4 series (all petaloid, but only the 2 inner series have nectaries—2 at base of each "petal") A 3 + 3, filaments sensitive at base and springing upwards when touched, anthers opening by 2 valves near top, $\underline{G}$ 1; berry red. See Fig. 77.

[*Magnolia*, several species cultd., one (*M. grandiflora*) is evergreen, dropping its leaves in June, the others are deciduous and the flrs. gen. come before leaves, flrs. large, white, scented, K 3 petaloid (soon falling), C 6-9, A ∞, $\underline{G}$ ∞, follicles with 1-2 seeds. "**Tea Plant**" (*Lycium*), with spines, a rambling shrub, 20-30 ft., leaves lanceolate flrs. reg., purplish, K (5), C (5), A 5, $\underline{G}$ (2), berry red or yellow.]

[**Mulberry** (*Morus*), 20-30 ft., leaves rough cordate serrate, flrs. greenish, unisexual, ♂ in long spikes, P 4, A 4, ♀ in heads, P 4 becoming fleshy round akene and forming a compound fruit superficially like that of Blackberry.]

The following are **evergreen**:—

Holly (*Ilex aquifolium*), 10-40 ft., with spiny (sometimes entire) leaves (in some varieties curled and crisped) and small unisexual flrs., ♂ and ♀ on separate trees; parts gen. in 4's, but sometimes in 2's K (4), C 4, A 4, G (4), ♂ flr. has a sterile ovary, ♀ flr. has 4 sta. with sterile anthers, and truly ☿ flrs. sometimes occur, fruit a 4-stoned drupe.

Spurge Laurel (*Daphne laureola*), 1-3 ft., leaves obovate—lanceolate leathery glossy, flrs. (Feb., Mar.) in drooping clusters, pale green, scented, structure as in Mezereon but P-tube longer (adapted to humble bees and moths).

Strawberry Tree (*Arbutus unedo*), wild in a few places in Ireland, often cultd., 10-20 ft., leaves oblong serrate, flrs. reg., cream-white, in drooping infl.; K (5), C (5), A 10, $\underline{G}$ (5), berry globular, orange red, with granular surface.

[**Tamarisk** (*Tamarix gallica*), on S. and E. English coasts but not native; 5-10 ft., a much-branched shrub with very slender feathery branches, leaves very small, flrs. small, pink or white, in spikes 1 in. long, K 5, C 5, A 5, G (3), seeds with tuft of hairs.]

[*Escallonia*, gen. with obovate serrate leathery leaves, bearing resinous dots below, and red drooping flrs., K (5), C 5 overlapping at edges to form a "tube" but free, A 5, $\overline{G}$ (3).]

[Most common **Rhododendrons** are varieties of *R. ponticum*, with shiny leathery oblong-lanceolate leaves and purple flrs., K (5), C (5), A 5 + 5, with each anther opening by 2 pores at top, G (5), capsule 5-valved.]

[*Kalmia*, in same Order (Ericaceae), has the 10 anthers held in as many conical pockets in the corolla, so that when flr. opens the filaments are bent like bows, and when an insect pokes for honey it releases the anthers, the stamens jerking up and shaking pollen over the under side of the insect.]

[*Ceanothus*, American shrubs often grown on walls, with more or less persistent serrate leaves, flrs. gen. blue in more or less globular clusters, allied to *Rhamnus*, K (5), C 5, A 5, $\underline{G}$ (3).]

V. Leaves Alternate, Simple, Lobed.—

Ivy (*Hedera helix*); examine plants growing on walls, tree trunks (Ivy is *not* a parasite), banks, etc., noting any differences in shape and arrangement of the leathery leaves (why leathery?), the down (= star-shaped hairs) on youngest stems and leaves, the climbing roots (developed at first only on side of stem away from light, but on old stems roots arise all round—probably to absorb moisture from air in damp woods), the racemose umbels of greenish-yellow flrs. (Oct.-Dec.), K (5) with very small lobes, C 5, A 5, $\overline{G}$ (5), black drupe.

Four species of **Ribes** grow wild in Brit.—*R. alpinum*, *R. grossularia* (Gooseberry), *R. nigrum* (Black Currant), *R. rubrum* (Red Currant), the three latter being much cultd. (White Currant is a variety of Red), [Crimson Currant (*R. sanguineum*) and Golden Currant (*R. aureum*) are favourite spring-flowering garden-plants,] all have lobed leaves, flrs. (Apr., May) in racemes (erect in *R. alpinum*, drooping in the others), inferior ovary with 2 parietal placentas, a more or less devd. rec.-tube and relatively large sepals, with smallish petals (alt. with sepals) and short sta. (opp. sepals) inserted on edge of rec., berry with few or ∞ gummy-coated seeds.

[**Plane Tree** (*Platanus*) has leaves rather like those of sycamore, but are *alternate* and the 5 lobes are more pointed, the bark is thrown off yearly in large thin plates, leaving light-coloured bare patches, at the base of the leaf-stalk are two stipules joined to form a tube surrounding the stem and leaving a circular mark on it after their early fall; the base of the stalk itself is scooped out to form a tubular cap which covers the bud, the sheath of the conical bud splits into 2 scales when the bud opens, besides the long-shoots, dwarf-shoots are formed which bear leaves and often end in a slender drooping axis bearing 3 or 4 globular infls. (Apr., May), ♂ or ♀, ♂ infl. compact, bearing groups of 3-6 sta., each group surrounded by scales, ♀ infl. has pistils in similar groups, each pistil having a long style, fruiting ♀ balls remain until next spring, when the nuts (ripe in Oct.) are set free.]

[**Tulip Tree** (*Liriodendron*) is allied to Magnolia, but has curious saddle-like leaves, truncated at the top, with 4 pointed lobes, large solitary flrs., K 3, C 6, A ∞, $\underline{G}$ ∞, samaras (cf. Magnolia).]

[**Fig Tree** (*Ficus carica*) has large bluntly 3- or 5-lobed deciduous leaves, flrs in a hollow capitulum (opening at top fringed with scales) with ♂ flrs at upper part of cavity and ♀ below (Fig 115 A), ♂ has P (3), A 3, ♀ P (5), G (2)]

[**Vine** (*Vitis vinifera*) has leaves 3-5-lobed and serrate branched coiling tendrils (each = a modified infl -axis), flrs reg , K (5), C 5 (joined at top and falling off as a hood), A. 5 (opp petals), $\underline{G}$ (2), berry]

VI Leaves Alternate, Compound.—

["**Virginian Creepers**" are species of *Vitis*, though often distd as "Ampelopsis" (leaves *compound*, palmate petals falling off *separately*) , *V hederacea* ("Ivy-leaved Ampelopsis") has coiling tendrils as in Vine, while *V veitchii* ("Self-clinging Ampelopsis") has non-coiling tendrils with each branch ending in a sticky disc]

The following have pinnate leaves —

[**Walnut** (*Juglans regia*) has 5-9 leaflets ; coarse bark furrowed in a network , the pith of the twigs is arranged in partitions separating it into chambers , the long drooping ♂ catkins arise singly from lateral buds which produce no leaves, the short erect ♀ catkins from end-buds which also produce leaves , each ♂ catkin scale has 2 side-bracts and a ♂ flr (P 3-5, A 6-20) , the ♀ spike has 1-4 flrs , each with a 1-ovuled inf ovary, 2 large stigmas, P = 4 scales on top of ovary, a toothed sheath below this (bracts), and a scale lower down ; fruit = a green thin fleshy layer which splits open irregularly, a 2-valved "stone," and a seed with thin coat, 2 large wrinkled cotyledons, each 2-lobed; on account of the membrane which projects in from the "stone," pointed radicle, and small plumule]

[**Ash Barberry** (*Mahonia*), allied to Barberry but with comp evergreen leaves , leaflets leathery, margins serrate or spiny , flrs as in Barberry, but no glands on petals]

[**Sumach** (*Rhus typhina*), 10-20 ft ; twigs thick, covered with velvety down ; leaves large (1-3 ft long) with 8-10 pairs of side-leaflets, serrate, turning red or purplish in autumn , flrs small, polygamous, in panicles, K (5), C 5, A 5, G (3) ; fruit hairy, dry, 1-seeded]

[**Tree of Heaven** (*Ailanthus*) is like Sumach in its large pinnate leaves, but the leaflets only turn brownish in autumn, often falling off and leaving the long bare petiole , flrs (Aug) greenish, polygamous, K (5), C 5, A 10 in ☿ flrs , but fewer in ♂ flrs , G 3-5 , samaras like those of Ash but smaller]

[*Koelreuteria*, a Chinese tree, 20-40 ft high in S Eng , deciduous, has large pinnate leaves with ovate coarsely-toothed leaflets (often rather deeply lobed) , flrs. yellow in panicles, K 5, C 4 (each petal with 2 scales at base), A 8-10, G (3) , polygamous , fruit a brownish bladdery capsule]

QUESTIONS ON CHAPTER XXV.

1 Name three English trees with which you are thoroughly familiar Describe the habit, branching, buds, bark, leaves, flowers, and fruit of each In what sort of situation would you expect to find each growing? Make your descriptions so clear that the trees could be easily distinguished and identified

2 Mention ten woody plants, either native or introduced into this country, which have evergreen leaves, distinguishing between the native and the introduced species. What is the general difference between the leaves of evergreen and deciduous woody plants? Can you give a reason for the difference?

3 Give the names and distinguishing characters of *two* evergreen shrubs selected from each of the following groups —(1) Conifers, (2) Monocotyledons, (3) Dicotyledons with free petals, (4) Dicotyledons with united petals.

4 Why does the normal branching of a tree follow its leaf arrangement? What is the arrangement in Apple, Gooseberry, Lime, Birch, and Lilac respectively? What influence has the formation of a terminal flower bud upon the subsequent growth of a shoot?

5 Explain as clearly as you can how plants heal their wounds What are the conditions that favour the healthy healing of cut surfaces?

6 How are pruning-wounds healed? How can the act of healing be encouraged and materially helped by the operator?

7. Make diagrams of the relation of "leaf-buds" and "fruit-buds" in any fruit-tree with which you are familiar, and also of the shoots produced by each How can you distinguish the two kinds of bud before they open?

8. What is the object and what do you suppose is the physiological effect of "pruning" fruit-trees? What are the conditions that favour the production of flowers in trees?

9 It is necessary, in order to be successful in any grafting operation, to bring together (at least at some part of the junction) a particular kind of tissue found in the stem, both of the stock and the scion What particular tissue is this, and why is it of so much importance in grafts?

10 What are the essential conditions of success in the progress of grafting? Give reasons for your answer

11. What are the conditions that favour the successful striking of a cutting, and why? There are certain differences in treatment between woody cuttings and herbaceous ones. Mention these differences and give reasons for same

12 Why is it that herbaceous cuttings require light, while woody cuttings may be grown, at least for a considerable time, in darkness?

13 Why is a moist atmosphere for the first few days helpful, and after that harmful, to most herbaceous cuttings?

14 In what way does overwatering affect the health of the cuttings?

15 Why does warmth, in most cases, cause starvation of the roots in woody cuttings, while it encourages root growth in herbaceous cuttings?

16 Mention some plants which are commonly propagated by (1) cuttings of their roots, (2) isolated pieces of their leaves

17 How are the following plants propagated (multiplied) apart from seeds?—Dahlia, Rose, Carnation, Aspidistra ("Parlour Palm"), Begonia, Pelargonium (Garden Geranium), Anemone, Lily of the Valley

18 In removing a bud from (say) a tuber for purposes of propagation why is it necessary to include in the cutting part of the substance of the tuber itself?

19 Draw and describe the appearance during winter of the buds of either Beech, Horse Chestnut, or some other tree Show by drawings the stages through which these buds pass in spring How can you hasten the natural opening of a bud on a cut branch?

20 Describe the general habit, leaves, and catkins of any kind of Willow (*Salix*) you know Make drawings to illustrate the structure of the flowers and explain how pollination occurs

21 How can you tell a Poplar from a Willow in winter?

22 Describe and explain the process of "pollarding" Poplars and Willows

23 Which Willows are used for basket-making? Where do these Willows grow?

24 Describe and compare the flowers of Willow and Poplar, giving sketches of their structure How are the flowers pollinated? Compare the pollination adaptations of Willows and Poplars

25 Describe the winter buds of a Willow or Poplar, with sketches

26 How can you distinguish from a distance (*a*) the Lombardy Poplar, (*b*) the Aspen?

27 How could you distinguish an Alder in winter? Where do Alders usually grow?

28 Describe, with sketches, the buds, young twigs, and leaves of Alder.

29 Describe the male and female catkins and flowers of Alder Give sketches At what time of year are the catkins formed? In what other catkin-bearing trees can both kinds of catkin be seen in winter?

30 Describe the fruit of Alder. In what respect do the fruiting catkins of Alder differ from those of other catkin-bearing trees? How could you distinguish an Alder "cone" from a Pine cone? Give sketches

31 Describe the appearance of a Hazel in winter How can you tell the Hazel (*a*) by its twigs and buds alone, (*b*) by its leaves alone, (*c*) by its fruits? Give sketches

32 Describe the male and female catkins and flowers of Hazel Give sketches

33 Describe the appearance of a Birch in winter How can you tell a Birch easily from a distance (*a*) in winter, (*b*) in summer? Why is the Birch called a "light-loving" tree?

34 Describe the catkins and flowers of Birch Which kind of catkin can be seen on the tree during the winter? Give sketches

35 Describe the ripe fruiting catkin of Birch How are the fruits dispersed? Give sketches

36 How can you tell an Oak in winter by its twigs and buds? Give sketches Why are the buds crowded at the tips of the twigs?

37 Describe the catkins and flowers of Oak When do the catkins first appear? Compare Oak with Birch, Hazel, and Alder in this respect Give sketches

38 Describe the fruit of Oak and compare it with that of Hazel

39 Describe the general appearance of a Beech (*a*) in winter, (*b*) in summer What makes the Beech cast such a dense shade? Why is Beech called a "shade-enduring" tree?

40 Describe the inflorescences and flowers of Beech, with sketches How do the inflorescences of Beech and Oak differ from those of Birch, Hazel, and Alder?

41 Describe the fruit of Beech, and compare it with that of Oak How are Beech and Oak fruits dispersed?

42 How would you distinguish an Elm *in winter* from a Beech, a Lime, or a Sycamore? Describe the leaves and flowers of the Common Elm, and compare with those of the Wych Elm

43 Describe the fruits of Common Elm and Wych Elm, with sketches How are Elm fruits dispersed? At what time of year do they ripen?

44 How is the Common Elm chiefly propagated, and how does i differ in this respect from the Wych Elm?

45 Describe all the external features seen on a Sycamore twig showing several years' growth Give sketches, and explain all the mark and structures you have drawn

46 Describe the flowers of Sycamore, and compare with those c Hedge Maple. Give sketches

47 Describe the fruits of Sycamore, and compare with those of Maple How can you distinguish between Sycamore and the true Plane-tre (*a*) in winter by bark and buds, (*b*) in summer by leaves and flowers?

48 Describe the leaves of Horse Chestnut, and compare with those o Sycamore Give sketches to show the relation between the two type of leaf

49 Describe the flowers of Horse Chestnut, and compare with thos of Sycamore. Note the adaptations for pollination

50 Describe the fruit of Horse Chestnut, and compare it with tha of Sweet Chestnut How may the latter plant be distinguished by it leaves and flowers?

51. Compare the external features of the shoot (excluding flower and fruits) of Sycamore and Horse Chestnut

52. Describe the mode of growth and the external features of th Lilac How is the Lilac usually propagated in gardens?

53 Describe the flowers and fruits of Lilac, with sketches

54 Describe the winter features of the Common Ash What othe common trees resemble it in some respects (state these), and how can the Ash be distinguished from them?

55 Describe the leaves and buds of the Ash, with sketches What distinctive features are shown by the twigs?

56 Describe the flowers and fruits of Ash, with sketches, and mention the adaptations for pollination and for dispersal.

57 How would you distinguish the following trees in winter:—Oak, Beech, Lime, Horse Chestnut, Elm, Lombardy Poplar, Ash, Alder? State how you can tell the annual segment of growth in a shoot.

CHAPTER XXVI.

CONIFERS

610. Scots Pine or "**Scotch Fir**" (*Pinus sylvestris*) is usually easy to distinguish from other Pines by the bluish-green foliage-leaves ("needles") arranged in pairs; the bark, orange-coloured except at base of trunk, where it is dark, the pointed cone, with a dull surface

The tree rarely exceeds a hundred feet in height In plantations or forests it shows a tall branchless stem (any signs of branches formerly present?) with an umbrella-like crown, but in the open it keeps the lower branches for many years The bark on the upper part of the trunk peels off in thin scales, leaving the surface orange-coloured, but near the base the scales remain attached for a long time, so that the bark here is thicker, rougher, and darker The structure of the buds, their mode of expansion, and the growth of the branches, have already been dealt with (Art. 321).

The stiff needle-like foliage-leaves are borne in pairs, each pair on a short or dwarf-shoot. Each leaf is slightly twisted; the upper side is flat, the lower curved, and the two sharp edges bear small teeth (how can one perceive these without using a lens?). The leaves live for three or four years, their duration depending on the amount of light they receive Each dwarf-shoot bears about a dozen small scales, forming a sort of sheath at the base of the two needles. The whole dwarf-shoot is cast off when the leaves are dead, giving the old twigs a rough scarred surface

Each year a circle of long-shoots is formed, so that the age of the tree (after the first three years of its life) can be told at once from the number of these circles of branches, or their remains if they have broken off. When the end-shoot is damaged, one (sometimes more) of the side-shoots grows out so as to replace it, in fact, one sometimes finds that one of the side-buds does not expand along with the others, but remains as an "emergency-bud"

The flowers (May, June) are of very simple structure; the male and female flowers are on the same tree The male flowers (Fig 171) are yellow egg-shaped bodies, about $\frac{1}{4}$ inch long, they represent dwarf-shoots, and are crowded together at the bases of the year's long-shoots Each male flower is in the axil of a scale, and has about four scales at its base, it consists of a slender axis bearing numerous spirally-arranged stamens Each stamen has a very short filament and a scale-like anther with a small crest at the free end, on the lower side are two pollen-sacs which open by longitudinal slits and let out the dusty sulphur-like pollen Shake a branch, or hit it with a stick, when the male flowers are ripe Each pollen-grain has two air-bladders, one at each side, which make the grain more buoyant by giving it a much larger surface without much extra weight

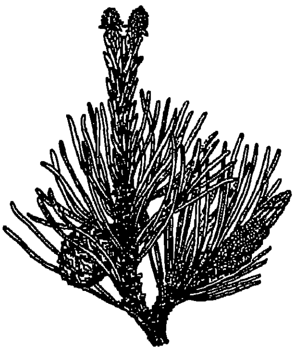

Fig 171 —The Pine, showing Cones (Sketch made in June)

The male flowers fall off after the pollen is shed, so that if the stem goes on producing male flowers year after year it shows a tufted arrangement of the needle-bearing dwarf-shoots, the tufts being separated by bare parts of stem which mark the former positions of the clusters of male flowers

Each female flower or "cone" (Fig 171) arises in the position of a lateral long-shoot Its bud grows rapidly in the first year and is then nearly spherical (about $\frac{1}{4}$ inch long) and stands erect on a short stalk At the base of the cone there are some small scales, and above these come the scale-like carpels Each carpel consists of a lower scale bearing on its upper surface a larger and thicker scale; the latter has two ovules ("young seeds") on its upper side near the base

While the pollen is being blown about, the axis of the cone lengthens so as to separate the scales and allow the pollen grains to reach the ovules. Then the stalk of the cone bends down, while the scales grow larger and thicker and become tightly packed together. Next year the cone begins again to grow bigger and becomes egg-shaped and pointed (about 2 inches long). In the third year the cone dries up, the scales gape apart (starting at the top of the cone), and the seeds escape. Examine cones of different years. Do all the scales of a ripe cone bear seeds? How many seeds are on each scale? Note the long thin wing attached to the seed, enabling it to be carried far by the wind.

The early germination of the seed has already been described (Art. 173). After the cotyledons have absorbed the endosperm and escaped from the seed, long needle-like leaves are produced, which *stand singly and directly on the stem*. In the second year single needles are produced at first, but they gradually dwindle upwards into scales; in the axils of the upper scales there arise the two-leaved dwarf-shoots. Thus the *young* Pine resembles *adult* Firs in having the foliage-leaves borne singly and directly on the stem.

[**611** Other species of Pine are often grown in Britain, and the commonest of these are fairly easy to distinguish from the Scots Pine. Of the kinds with two needles on each dwarf-shoot, the **Black** or **Austrian Pine** has larger cones, longer (up to 7 ins.) and darker green needles, darker and coarser bark; the **Stone** or **Umbrella Pine** has long (up to 7 ins.) but slender and bright green needles, larger and more rounded cones (about 5 × 4 ins.); the **Cluster Pine** has still longer leaves (up to a foot), thick and fleshy, cones in clusters of six or often more, long egg-shaped (up to 8 ins. long). The **Weymouth Pine** has its needles in *fives* on the dwarf-shoots, each needle about 4 ins. long, cones curved and about 5 ins. long.]

[**612. Larch** (*Larix europaea*) is easily recognised by the numerous short thick dwarf-shoots, very conspicuous in winter when the tufted leaves have fallen (Larch differs from most other Conifers in *not* being evergreen). See Art. 322.

The tree rarely exceeds ninety feet in height, and the main branches, which are not arranged in regular circles as in Pine, spread out at first horizontally from the trunk, or bend down, but turn up at the ends, while the finer branches mostly hang downwards. The Larch is a light-demanding tree, and has a tapering crown, the lower branches die much sooner than in Pines when the trees are closely planted.

The foliage-leaves (about 1 in. long) are soft, flat, light green, with a ridge along the lower side and a blunt tip. Those on the long-shoots are arranged singly and are more pointed, while those on the dwarf-shoots are crowded to form tufts (20 to 60 in a tuft) and are longer and narrower (Fig 172). In autumn the needles turn brown and fall off.

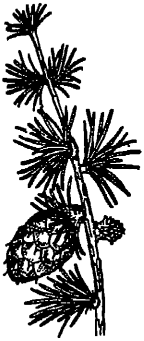
Fig 172.—The Larch, with Cones.

The male (yellow) and female (red) flowers, which occur on the same tree and open in spring, arise from buds (resembling vegetative buds) on the ends of the dwarf-shoots. The male flowers are solitary, but otherwise resemble those of Pine in general structure; the pollen grains have no air-bladders. The female flower has below it a tuft of needles (none are formed below the male flower) which gradually pass above into the scales at the base of the flower itself. It is always erect or nearly so, if the branch itself is not erect, the stalk of the female flower curves so as to bring the flower into the right position. Its structure is essentially the same as in Pines, except that the scales which bear the seeds are at first much smaller than the red lower scales (bracts), the latter being alone visible from outside. However, after fertilisation the bracts wither while the seed-scales grow actively, close up, and become woody (but not thick as in Pine).

The cone ripens in the first year and is egg-like (1 to $1\frac{1}{2}$ ins. long), it opens in the following spring, but the old cones remain on the tree for many years. The seeds are winged but small, the seedling during the first few years of its growth is *evergreen*, the upper leaves at least remaining on the plant during winter.]

613. The only relatives of the Larch are the **Cedars**, the three kinds of which are all planted for ornament in Britain—Cedar of Lebanon, Deodar, Atlantic Cedar. The Cedars resemble the Larch in general structure, especially in having numerous needles in the tufts on the dwarf-shoots, but the needles are *evergreen* (lasting for three to five years) and much more rigid (why ?), besides being darker green; the male flowers are larger (about 2 ins long), the cones larger (about 3 ins. long) with short broad thin scales In the **Cedar of Lebanon,** the branches are practically horizontal; in the **Deodar** or **Indian Cedar** they are more drooping, the whole tree is lighter in colour owing to the grey bark, the leaves are larger and more bluish, in the **Atlantic Cedar** the branches are inclined upwards.

614. Coniferae.—Most of the other Conifers grown in Britain have only ordinary long-shoots carrying the foliage-leaves In **Maiden-hair Tree** (*Ginkgo,* now placed in a group apart from Conifers), however, there are dwarf-shoots bearing tufted leaves and flowers, it has fan-shaped deciduous leaves **Swamp Cypress** (*Taxodium*) also has deciduous leaves, it grows best in moist places, and its roots send up erect conical branches, covered with lenticels, which act as aerating organs

The Conifers may be divided roughly into two groups —(1) those with scaly buds and numerous stamens and carpels in the cones; (2) those whose buds are not scaly and which have few stamens and carpels

To the first group belong the Pines, Larch, Cedars; also **Spruce Fir** (*Picea excelsa,* leaves 4-angled and spirally arranged on twigs, cones drooping cylindrical about 5 ins long, cones fall off entire), **Silver Fir** (*Abies pectinata,* leaves flat and appearing on twigs as if combed out to form two series lying horizontally on each side, cones erect with scales falling off separately and leaving cone-axis bare), **Douglas Fir** (*Pseudotsuga,* like Silver Fir in having the leaves flat and the bracts projecting beyond seed-scales, but like Spruce in not having the leaves spread out on each side of twigs, cones drooping, seed-scales falling off), **Monkey Puzzle** (*Araucaria,* branches in regular whorls of 6-8, leaves in more or less definite whorls of 8 with stiff spiny tips, ♂ and ♀ cones on separate trees, globular at ends of branches).

To the second group belong *Taxodium* and Juniper, also many others (mostly shrubs or small trees), such as **Arbor Vitae** (*Thuja,* scale-like leaves in 4 rows, flattened and fused with stem except at tip, twigs flattened and the branches usually horizontal, cones oblong, flattish, small), **Chinese Arbor Vitae** (*Biota,* like *Thuja,* but denser in habit, leaves furrowed along the middle, branches mostly turned upwards, leaves smaller and lighter-green), **Common Cypress** (*Cupressus,* twigs 4-angled, leaves in 4 rows, cones globular).

615. Native British Conifers.—Several other Conifers are cultivated in this country, but the only native (*i e* not introduced in historic times) plants of this division are the Scots Pine, Yew, and Juniper

The **Yew** (Fig. 173) is an evergreen tree with a massive trunk and spreading branches The narrow, dark green leaves are glossy above, slightly curved, and are thickly set on opposite sides of the branches

The male and female flowers are produced on separate trees, on the under side of the twigs. The male flower consists of a scaly bud with a tuft of stamens (each umbrella-like, with about six pollen-sacs) projecting above its summit, the female flower does not produce a cone, but somewhat resembles a small acorn (up to ½ inch long) in form, and develops into a red cup-like "fruit," containing a small "nut," the top of which is exposed The "nut" is, of course, the seed, the cup is an extra seed-coat (*aril*).

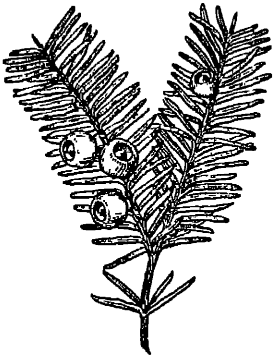

Fig 178 —The Yew, with Fruits

The **Juniper**, a bush with crowded narrow prickly leaves in whorls of three, about an inch long, also has its male and female flowers on separate plants, in axils of leaves The male flower has the stamens in 4 or 5 whorls (3 stamens in a whorl), each stamen has 3 pollen-sacs, the female flower (small, bud-like, green) has a few scales surrounding a whorl of three erect ovules. The black fleshy "berry," ripe in the autumn of the second year, is about ⅓ inch long, nearly globular, and the fleshy part is formed by the scales around the seeds themselves

QUESTIONS ON CHAPTER XXVI

1. Describe the appearance of a twig of Scots Pine examined in winter. Give sketches

2. Describe a Pine twig as seen in May or June. What is observed if the twig is shaken at this time?

3 Make a careful sketch showing the various parts seen at the end of a Pine twig in June:—male flowers, young dwarf-shoots, and young cones

4. Why does a Pine branch show whorls of branches? Why is there often a bare piece of stem just above each of these whorls?

5. Describe the various structures which may arise from the resting-buds of the Pine.

6 For how long may the foliage-leaves (needles) remain on a Pine tree? What other leaf-structures are found on a Pine shoot?

7. Describe the structure of a male flower of Pine, with sketches.

8 Describe the appearance and structure of a Pine cone at different stages (first year, second year, third year, etc), with sketches.

9 How are the seeds of the Pine dispersed? What other plants have *seeds* provided with a similar dispersal mechanism?

10 How could you distinguish a Larch from a Pine (*a*) in winter, (*b*) in summer?

11 Describe the general appearance of a Larch twig, with sketches, and compare it with a Pine twig.

12 Describe the male and female inflorescences of Larch, with sketches, and compare with those of Pine

13 How do Pines and Larches differ from Firs and most other Conifers?

14 Describe the seedling of a Pine, showing how the adult arrangement of the leaves is acquired.

15 Describe the leaves, flowers, and fruits of Yew and Juniper, and point out their peculiarities.

CHAPTER XXVII.

THE ECOLOGY OF PLANTS.

616. Plant Ecology.—Having now gained some practical knowledge of the structure and life-processes of plants, you should proceed to study the vegetation of your own district and that of any district you may visit. The main object of this study should be to find out as much as possible about the various ways in which plants are influenced by, and adapted to, their surroundings or "environment." The term **Plant Ecology** simply means "the study of plants in their homes." Much can be done in this direction even with limited knowledge of the classification of plants, but the more you know of structure, physiology, and classification, the better will you be equipped for the study of plants from the ecological point of view. It is an easy task to learn how to distinguish the commoner plants, especially those which show striking adaptations to some special locality or "habitat."

There are various books which enable one to identify any flowering plant met with in this country. The most complete of these "Floras" are Bentham and Hooker's *British Flora* and Hooker's *Student's Flora*; the former is illustrated, and is the more expensive of the two. Smaller books, less complete and less expensive, are Hayward's *Pocket Flora* and Watts's *School Flora*. A still cheaper, but extremely useful, Flora is Fox's *How to find and name Wild Flowers* (Cassell, 1s. 6d.), which may be recommended to beginners in the work of plant identification. *Plant Biology* (Clive, 3/6) contains a summary of the chief Orders (Appendix III.), together with monthly lists of plants in flower (Appendix IV.).

617. Terms used in Plant Ecology.—You must often have noticed that various plants grow together, in a sort of society or community, in certain localities—*e.g.* in water or in marshes, on moors and in bogs—evidently because they "like" or "prefer" (that is, are adapted to) the same kind of soil, the same conditions of dryness or wetness, the same amount of light or of shade, etc Such groups of plants, growing together in a sort of community, may be called Plant Associations

There are four main ecological plant-types. At one extreme we have plants adapted to life in ponds, rivers, ditches, growing partly or entirely submerged in water. These true water-plants are said to be *hydrophilous* (*i.e* "water-loving"), and are termed **Hydrophytes.** Plants which grow in marshes or swampy ground, on river-banks or on ditch-sides, or in damp shady woods, are said to be *hygrophilous* ("moisture-loving") plants, or **Hygrophytes.**

At the other extreme we have plants which are adapted for life under conditions of "physiological" drought—that is, under such conditions that it is necessary to check or greatly reduce the rate of transpiration, or to store up water, or to do both, because the water supply is scanty or runs through the soil too quickly for the roots to absorb much of it, or because the water cannot be absorbed freely on account of the presence of excessive amounts of dissolved salts or of peaty matter, or because the plant grows in places exposed to high drying winds, or in cold soil, or exposed to excessive light.

A little reflection will show that any of these causes will lead to the development of adaptations for reducing transpiration or for storing the scanty or precarious supply of water which the plant can absorb In other words, such plants will be *xerophilous* ("drought-loving") plants, or **Xerophytes.** Xerophytes occur on heaths and moors, also in the boggy places which accompany them, on high mountains with an Alpine flora; in sandy localities; on chalk downs, on the sea-coast (cliffs, rocks, sandy beaches, sand-dunes, salt-marshes); and in dry woods or plantations of Pines, Firs, Larches, and other Conifers.

Between xerophytes and hygrophytes we find a great many intermediate forms (**Mesophytes**), comprising, in fact, the majority of British plants, which grow in meadows, pastures, cultivated fields, and in damp woods and plantations of deciduous trees (Beech, Oak, Birch, etc.) These plants show no decided xerophilous or hygrophilous characters, though some approach xerophytes in form and structure and others approach hygrophytes

Woody perennials (trees and shrubs) with deciduous leaves show distinctly xerophilous characters in winter (the protected winter buds, cork-covering of stems and of leaf-scars, cork-layer closing up the lenticels), while in summer they bear thin leaves like those of mesophytes or hygrophytes It has been proposed to call such plants, which are more or less hygrophilous in summer and xerophilous in winter, **Tropophytes** (*i e* "changing plants") This applies only to deciduous plants, evergreen land-plants are more or less strongly xerophilous in character, their leaves being usually tough, thick, and leathery (*e g*. Holly), or needle-like (*e g* Pine), with thick cuticle and sunken stomates.

It must be remembered that no hard-and-fast lines can be drawn between these types. For instance, some aquatic plants can, when the stream or pond dries up, continue to live and grow, sometimes even more vigorously, in the air, thus changing from hydrophytes to mesophytes The same species of plant may be found growing under hygrophilous or xerophilous conditions in different localities In each case the structure of stem and leaf, as well as the form of the leaves and the general habit of the plant, become modified to suit these different modes of life Coast-plants can, in many cases, be grown in ordinary soil, and develop thin instead of fleshy leaves.

618. Environment.—In the study of Plant Biology you should always be on the alert to ascertain whether the differences in form and structure presented by different plants can be accounted for by differences in their mode of life and habitat. This study requires a sound practical knowledge of the morphology and physiology of plants. All the factors that make up the environment must also be taken into account. These factors fall into two main groups · (1) the **climatic** factors, including temperature, rainfall, light, (2) the **edaphic** factors, including the physical and chemical characters of the substratum—*i e* in most cases the soil The environment includes not only the non-living, but also the living surroundings The former include (*a*) temperature, (*b*) moisture, (*c*) light, (*d*) soil or other medium, the latter include (*e*) other plants, (*f*) animals, (*g*) man

619. Water-Plants are subject to less extremes of temperature than land-plants, for the water in which they grow takes longer to be heated and longer to cool The percentage of carbon dioxide in water is higher than in air, since this gas dissolves readily in water The submerged leaves of a water-plant are usually either long and strap-like, as in *Glyceria fluitans*, a water-grass, or narrow and arranged in whorls, as in Water Starwort (*Callitriche*), or divided into numerous fine threads, as in Water Buttercups. These submerged leaves have chlorophyll in the epidermis, which bears no cuticle, so that water containing dissolved salts and gases can pass in freely Since the submerged parts get their salts, oxygen, and carbon dioxide directly from the water, there are no stomates, nor does the stem contain many wood-vessels, and the roots serve chiefly to fix the plants to the bottom, having few or no root-hairs, since root-absorption is not required. As we have seen, a land-plant requires to have its stem and leaves strengthened by hard tissue, arranged so as to resist the strains caused by weight and by wind In a water-plant the weight is, of course, supported by the water, and the only strain to which fixed submerged plants are subject is a pulling-strain due to movement of the water, especially in fast streams For these reasons there is little or no special mechanical tissue outside of the vascular bundles, and the latter are placed in the centre of the submerged stem, as in the *root* of a land-plant Leaves which float on the surface of the water are entire and rounded or slightly lobed (Water-lilies, Pondweeds, Duckweed, and some Water Buttercups), and bear stomates on their upper surface, which is covered with cuticle or wax so as to prevent wetting These floating leaves have the same structure as those of land-plants, but the air-spaces are very large and are continuous, with air-passages running down the leaf-stalk to the submerged stem and roots Air-spaces are present in submerged plants too, as well as in the stems of plants which grow with only their lower parts in the water—*e g* Mare's-tail, Rushes, Sedges. In submerged plants these air-spaces enable the plant to float upright, but they also convey air to the lower parts growing in deep water or in mud, where little or no oxygen is present for respiration

Since a submerged plant gets water, salts, carbon dioxide, and oxygen so easily, and lives in very favourable conditions generally, it grows rapidly, branches freely, and reproduces itself largely by vegetative means, chiefly by the decay of the older parts setting the branches free, or by branches breaking off The water-plants of tropical regions grow continuously all the year round, not being hampered by either a cold or a dry season In temperate regions growth is interrupted by the winter, and various methods of perennation occur (practically all water-plants are perennial) In some cases—e g *Callitriche*—the plant remains unaltered, merely sinking to the bottom, in Water-lilies, food is stored up in the rhizome, in Arrow-head, tubers are formed A very common mode of perennation is the formation of winter-buds, which are developed at the ends of the branches These buds are large, their leaves contain reserve food; they drop off and remain at the bottom during winter, growing up in the spring Winter-buds of this kind occur in Water Milfoil, Water Violet, Bladderwort, Frog-bit, and various species of *Potamogeton* (Pond-weed)

What we may term "typical" water-plants grow with the entire shoot (except, in most cases, the flowers) under water and the leaves submerged or floating Some plants can grow either submerged or on muddy soil with their shoots in the air In such amphibious plants the leaves of the land form are broader, and the stem- and leaf-structures resemble that found in ordinary land-plants

Many water-loving plants can be grown on land, either by transplanting them to ordinary soil or by sowing the seeds in soil · in the former case the new shoots formed differ from the water-form in regard to leaf-shape and the leaf- and stem-structure, in the latter case the seedlings produce at first some leaves of the aquatic type, and later bear broad land-leaves These experiments should be tried, as well as the reverse kind of experiment—*i e.* transplanting, or germinating seeds of, land-plants in mud, very wet soil, or in water. In some cases the change from land-plant to water-plant can be brought about, especially with plants which grow ordinarily in damp places.

Some plants grow in shallow water, but send up their leafy and flowering shoots into the air These will be included under the heading of "Marsh-plants"

More than half of the British species of the Buttercup family live in water or in marshy places, the name Ranunculus ("little frog") refers to the moisture-loving character of many Ranunculaceae The types we have studied show a gradual transition from land plants to water plants Can you arrange the common Buttercups and the other plants given in this chapter so as to illustrate this gradual transition, from your own observations? Note the structural features which mark the transition the air-spaces in Little Celandine and Marsh Marigold (the latter a more decidedly moisture-loving plant than the former), the presence of abundant stomates on the upper side of the leaf in these plants, etc

How can these features be explained? Everything we know of water- and marsh-inhabiting Flowering Plants shows that these have descended from land plants They probably began by growing in damp places, like some Buttercups; then became adapted to more permanently moist places, acquiring large air-spaces for better aeration and having stomates as abundantly on upper leaf-surface as on lower, or more so, since there was no need to check transpiration—this stage is illustrated by Little Celandine.[1] Then, driven by the struggle for existence, the plants came to grow in marshes or standing waters and developed still more pronounced marsh characters, and finally took to growing in water, with the leaves submerged or floating

The commoner water plants, with submerged or floating leaves, or both kinds, which grow in ponds and streams include Quillwort (*Isoetes*), Canadian Water-weed (*Elodea* or *Anacharis*), Pondweeds (*Potamogeton*, *P. natans* with stalked oblong leaves being the commonest species), Frog-bit (*Hydrocharis*), Duckweeds (*Lemna*), White and Yellow Water-lilies (*Nymphaea*, *Nuphar*), Horned Water-weed (*Ceratophyllum*), Water Crowfoots, Water Starworts (*Callitriche*), Water Milfoil (*Myriophyllum*), Water Violet (*Hottonia*), Bladderwort (*Utricularia*), Shore-weed (*Littorella*), Water Lobelia (*Lobelia dortmanna*) For descriptions of these plants see a British Flora, *e.g* Hooker's *Student's Flora*.

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[1] It is interesting to note that the stomates of bifacial leaves are, as a rule, confined to the lower side in evergreen leaves; found on both sides (more abundantly on lower side) in most British plants, more abundant on upper side in many marsh plants, confined to upper side of floating leaves and of Grass leaves In cylindrical leaves—*e.g* Onion—they are evenly scattered, and this is also the case with most needle-like leaves—*e.g* Pines

620. Marsh-Plants.—Between submerged water-plants, moisture-loving plants, and ordinary land-plants there is every stage of transition We can, however, distinguish between truly aquatic plants and those characteristic of marshes and bogs The former are permanently submerged in water, whereas bogs and marshes occur where the substratum alternates between long periods of submergence and shorter periods of more or less complete drying-up. As we have seen, submerged water-plants get oxygen and carbon dioxide, in addition to salts, from the water, hence they occur mainly in water which is moving, or at least often removed. On the other hand, water-plants with floating or with aerial leaves can grow in stagnant pools or ditches where there is little oxygen, and where organic acids and marsh gas are abundant. The same is true of marsh or bog plants, whose characteristic feature is that their lower parts, buried in the stagnant mud, are adapted to life in water, while their upper parts, exposed to the air, either resemble those of ordinary land-plants or have leaves adapted to withstand periods of drought

The commoner marsh plants, which grow on the margins of ponds and streams, or with their lower parts in water, but usually have all or most of their leaves above the water—not submerged or floating—include Pillwort (*Pilularia*), Horsetails (*Equisetum*), Sedges (*Carex*), Rushes (*Juncus*), Bulrushes (*Typha*), Bur-reeds (*Sparganium*), Water Plantain (*Alisma*), Arrowhead (*Sagittaria*), Flowering Rush (*Butomus*), Marsh Arrowgrass (*Triglochin palustre*), Yellow Iris, Marsh Orchis, Willows, Alder, Water Docks (*Rumex conglomeratus*, *R hydrolapathum*), Water Pepper (*Polygonum hydropiper*) and other water-loving Polygonums (*P amphibium*, *P bistorta*, *P persicaria*), Blinks (*Montia*), Ragged Robin, Water and Marsh Stitchworts (*Stellaria aquatica*, *S. uliginosa*), Water-cress (*Nasturtium*), Lady's-smock (*Cardamine*), Water Avens, Meadow-sweet, Golden Saxifrage, Purple Loosestrife (*Lythrum*), Willow-herbs (*Epilobium*), Water Purslane (*Peplis*), Mare's-tail (*Hippuris*), Marsh St John's-wort (*Hypericum elodes*), Water Dropworts (*Oenanthe*), Wild Celery (*Apium*), Water Parsnips (*Sium*), Water Hemlock (*Cicuta*), Knotted Marshwort (*Helosciadium*), Marsh Pennywort (*Hydrocotyle*), Brook-weed (*Samolus*), Yellow Loosestrife (*Lysimachia vulgaris*), Moneywort or Creeping Jenny (*L. nummularia*), Water Forget-me-Not, Marsh Woundwort, Water Mint, Pennyroyal, Gipsy-wort, Water Speedwell (*Veronica anagallis*), Brooklime (*V beccabunga*), Marsh Speedwell (*V. scutellata*), Red Rattle (*Pedicularis palustris*), Marsh Figwort (*Scrophularia aquatica*), Marsh Hawk's-beard (*Crepis paludosa*), Water Ragwort (*Senecio aquaticus*), Hemp Agrimony (*Eupatorium*), Bur Marigold (*Bidens cernua*), Marsh Cudweed (*Gnaphalium uliginosum*), etc.

621. Bog-Plants.—The typical bog occurs on heaths and moors, associated with Heather and other heath-plants, and its vegetation consists of peat-forming and peat-loving plants The distinctions between a marsh and a bog are fairly clear in most cases, though there are transitions from one to the other The typical marsh occurs on low ground, its water is rich in mineral substances, especially lime, and its plants grow rapidly, either becoming tall or remaining low, but producing numerous leaves and branches each year In the typical bog, the water is poor in lime and other salts, and the plants are mostly slow-growing and of low stature Peat-bogs, like the heaths or moors on which they occur, are found at all heights, from a few feet above sea-level up to three thousand feet The peaty soil in which bog-plants grow is not sufficiently aerated for the proper formation of nitrates, so that although such soils (bog, peat, morass) often appear on analysis as though they should be extremely fertile, very little of the materials they contain is directly available to serve as plant-food

Most bog-plants have more or less well-developed xerophilous characters, due largely to the excess of peaty acids, which makes water-absorption difficult Mosses, especially the Bog-mosses (*Sphagnum*), of which many species and varieties have been distinguished, play an important part in the formation of bogs. The Bog-mosses, whose appearance and remarkably spongy character are well known to all who have walked over our moors, are specially adapted for storing water The leaf of a Bog-moss consists of a single layer of cells, which are of two kinds (1) large empty cells with pores on the walls, (2) small green cells The green cells are long and narrow, forming a network, each mesh of which is occupied by one of the empty cells; the green cells carry on the living functions, while the large clear cells store up water Each plant branches and grows upwards, while the lower parts die and lose their green colour, but are preserved from decay by the absence of oxygen and the presence of the peaty acids In this way great masses of peat are formed.

The flowering plants found in bogs include Ericaceae (Ling, Heather, Bilberry); Sedges, Rushes, and Grasses, mostly different from the kinds found in marshes or wet meadows; Bog Asphodel, Bog Orchids, Bog Myrtle, Grass of

Parnassus, Bog Cinquefoil (*Comarum palustre*), Sundews (*Drosera*), Marsh Gentian (*Gentiana pneumonanthe*), Bog-bean (*Menyanthes*), Bog Pimpernel, Butterwort, Bladderwort.

As already stated, peat is very poor in available plant-food, and this fact largely accounts for (1) the xerophilous character of most bog-plants, (2) the presence of insectivorous plants like Sundew and Butterwort in bogs.

622. Moorland Plants are exposed to high winds, which not only increase transpiration, but prevent the growth of trees. This is not so marked on low moors (heaths), where such trees as Pines and Birches flourish, but on high moors the entire vegetation is dwarfed and stunted. On the highest parts of a moor, like those of Yorkshire and Devonshire (Dartmoor), the rainfall is high and frequent. On the summit of Dartmoor (including the area around Cranmere and Fur Tor, where all the great rivers of Devon arise from an intricate network of boggy crevasses which gradually give rise to streams), the aspect of the vegetation is dreary in the extreme, both in summer and winter, though livened in early

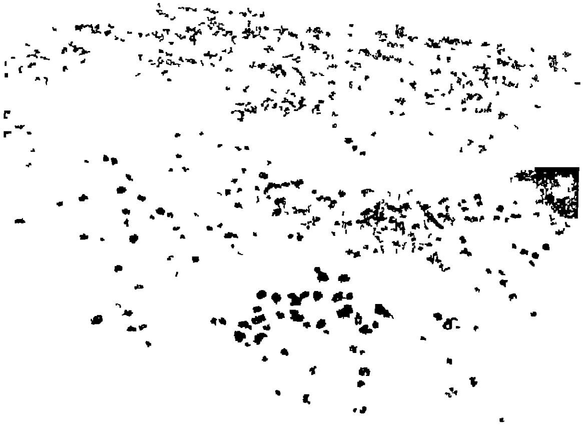

Fig 174.—Cotton-Sedge (Cotton-"grass") on a Boggy Moor.

summer by the white fruits of the Cotton Grass, which form snow-like patches The chief plants found on this boggy plateau are Cotton Grass and Ling (*Calluna*), mixed with tufted Grasses having narrow rolled-up leaves, together with cushions of dry Mosses, while the wetter parts consist almost entirely of Bog-mosses Farther down, as well as on the wind-swept outlying ridges of the moor, the dominant plant is usually the Bilberry (*Vaccinium myrtillus*) in the drier parts, with Sedges, Rushes, and Bog-mosses in the swamps and along the water-courses On low-lying heaths we find chiefly Ling and Heaths (*Erica cinerea, E tetralix*), Gorse, Bracken, with low creeping plants which shelter under these—*e.g.* Tormentil, Heath Bedstraw—and in the wetter parts the various bog and marsh plants already mentioned.

The leaves of Ling, Heaths (*Erica*), and Crowberry[1] are rolled up so that the lower epidermis (bearing the stomates) forms the inside of a tube which is open to the air by a narrow slit (seen as a white line along the lower side of the narrow leaf); the edges of the leaf bear hairs, which still further hinder the escape of water-vapour from the leaf Bilberry has broad, thin leaves, but these fall off early, and the ridged green branches carry on photosynthesis without exposing much surface for transpiration Sedges and Rushes have narrow leaves with thick cuticle, while heath-grasses bear on their upper surface triangular ridges, and can roll up longitudinally in dry weather so as to expose a very small surface for transpiration (the green tissue, with stomates, lines the furrows between the ridges). The leaves of Bracken-plants growing on heaths have thicker cuticle, less spongy tissue, and fewer stomates than those of Bracken growing in moister and more sheltered places, the same applies to other species which grow both on heaths and in less exposed places

623. Humus Plants.—Some of these simply prefer the humus as a medium on which to grow This applies to the Crowberry (*Empetrum nigrum*), the Cranberry (*Vaccinium*), and the Rhododendron. Others, however, are saprophytes, and use the humus as a source of food. They are aided in this by the presence of symbiotic fungi (mycorhiza) on their roots, which play the part of root-hairs, and after decomposing the humus hand over all or a portion of it in a suitable form to the plant. Plants of this kind commonly have their foliage-leaves reduced to mere scales, as in the Bird's-nest Orchid. When (as in Heather) the leaves are fully developed, the mycorhiza probably enables the plant to absorb nitrogen from the humus, and not carbon.

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[1] *Empetrum nigrum*, a heather-like plant in general appearance, though not belonging to Ericaceae It is rare in the south of England, but is abundant on some moors in the north

Humus collects in most bogs and swamps, but here it is the water which is of primary importance in influencing distribution.

624. Chalk-Plants.—Of plants which prefer or are in some districts entirely restricted to calcareous soils, may be mentioned the wild Columbine, the Lily of the Valley, the Fly and Bee Orchis, the common Rock Rose, the Bloody Crane's-bill (*Geranium sanguineum*), Stinking Hellebore (*Helleborus fetidus*), Traveller's Joy (*Clematis*), Yellow Gentian (*Chlora*), *Campanula glomerata*, Whitlow-grass (*Draba muralis*), Dyer's Weed (*Reseda lutea*), Wild Flax (*Linum perenne*), Dogwood (*Cornus*), Wayfaring Tree (*Viburnum lantana*), Mouse-ear Hawkweed (*Hieracium pilosella*), Privet (*Ligustrum*), Verbena, Deadly Nightshade (*Atropa*), Hound's Tongue (*Cynoglossum*), Pasque Flower (*Anenome pulsatilla*).

Chalk soils are usually dry, and, in dry continental climates, plants which grow in almost all soils in England may be unable to develop on the calcareous regions of the continent. Thus the white Birch, *Hypericum pulchrum*, *Stellaria holostea*, *Galium saxatile*, and Broom are all absent from the calcareous Jura mountains, but grow freely upon the Vosges, on which the soil is formed of decomposed granite, and also in marl soils in which the presence of some clay renders the soil more retentive of moisture.

625. Pure Clay does not form a soil preferred by any flowering plant, and is highly unsuitable to most. When dry the soil bakes hard, and is almost impenetrable by the roots, while the very fact that when moist it is highly retentive of water renders it difficult for the plant to absorb sufficient water unless the soil contains a large amount In this case the soil is very badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply If mixed with sand, chalk, or humus, however, the soil is much improved, and many plants will survive periods of drought on such soils, whereas they may perish on more porous ones Such plants as Lily of the Valley (*Convallaria*), Lesser Celandine, Wood Sanicle, Coltsfoot, Primrose and Cowslip, Bittersweet (*Solanum dulcamara*), Yellow Dead-nettle (*Galeobdolon*), Garlic, Early Purple Orchid (*Orchis mascula*), Blue-bell (*Scilla nutans*), are found, in some districts at least, to prefer soils containing a good deal of clay

626. Sand-Plants.—These include (*a*) those plants which prefer merely a sandy soil, and (*b*) those of the sea-coast (**strand-plants**) which have adapted themselves to the presence of salt Many such plants grow equally well in ordinary soil, but lose certain of their characteristics, and probably would not survive if left open to free competition Practically all such plants have strongly xerophilous characters, for example, reduced leaf-surface, thick fleshy or prickly leaves and stems, stunted habit, thick cuticle, deeply sunk stomata, etc Sand-plants, pure and simple, are often very prickly, thorny, or hairy, whereas hairs are usually absent or few in number on strand-plants

As instances of sand-plants, the following may be mentioned Mousetail (*Myosurus*), Sand Spurrey (*Spergularia*), Stork's Bill (*Erodium*), Broom, Wormwood (*Artemisia*) Golden Rod (*Solidago*), Wood Sage (*Teucrium*).

627. Strand-Plants.—The plants which grow along our shores, either on sand or in mud-flats (salt-marshes), are sometimes called *Halophytes*, or saline-plants. They either prefer salty soil, or grow here because their competitors are more sensitive to salt and are unable to follow them. All strand-plants are more or less xerophilous in character, and this is also the case with regard to plants growing on salt-marshes or muddy shores Here the plant strives to reduce its need of absorbing water to a minimum, so that it shall not absorb too much salt. Hence the plants are fleshy or leathery, the cuticle is thick, the stomata often sunken, and the leaf-surface often reduced or spiny. Since high winds often prevail, the flowers are usually small, and the seeds are rarely winged, but there are exceptions to both these rules. the Sea-poppy has large yellow flowers, and the Sea-thrift has a persistent membranous calyx, which forms a funnel-like wing on the fruit

Coast-vegetation varies according to the nature of the soil, rocky shores, sand-banks, or "dunes," and muddy salt-marshes have each their own typical plants, though there are often transitions from one to the other On rocks and cliffs we find Sea-plantains (*Plantago maritima* with entire fleshy leaves, *P. coronopus* with lobed hairy leaves), Scurvy-grass (*Cochlearia*), Samphire (*Crithmum*, an Umbellifer, with many-lobed fleshy leaves), Sea-thrift (*Armeria*, with heads of pink flowers), Sea Campion (*Silene maritima*) Several of these plants (Thrift, Sea Campion, Scurvy-grass, and *Plantago maritima*) occur also on high hills inland, but not in the low-lying parts between the hills and the coast

On sandy shores, close to the sea, we find such plants as Sea-poppy (*Glaucium luteum*, with large yellow flowers and very long fruits), Orache (*Atriplex*, several species, shrubs with mealy leaves and spikes of small green flowers), Sea-beet (with fleshy swollen tap-root), Sea-blite (*Suaeda*, with cylindrical fleshy leaves), Saltwort (*Salsola*, rather like Sea-blite, but with a spine at the tip of each leaf), Sea-convolvulus, Sea-holly (*Eryngium*, an Umbellifer with leaves like those of Holly, and small blue flowers in heads like those of Teazle), Sea-purslane (*Arenaria peploides*, with crowded decussate ovate fleshy leaves), Seakale (*Crambe*, with thick fleshy rhizome, leaves 6 ins to 10 ins long, stalked broad, fleshy; flowers white, in corymbs); Sea-rocket (*Cakile*, like *Crambe*, but annual, leaves only 2 ins. to 3 ins. long), Sea-spurge (*Euphorbia paralias*, with woody rhizome, fleshy leaves, milky juice as in other Spurges), Sea-milk-wort (*Glaux*, belonging to Primulaceae, a small fleshy plant with creeping rhizome, narrow leaves in pairs, flowers small, axillary, with white or pink calyx, no corolla, capsule opening by five valves) All these plants have either fleshy or leathery leaves, and are either annuals, or, if perennial, have long tap-roots or rhizomes by whose upward growth the plants keep above the surface and avoid being buried by the shifting sand Further back from the sea we come to sand-dunes in which grow various grasses and sedges. The most conspicuous grass is the Marram-grass (*Ammophila*), whose long rhizomes creep in the sand and send up tufts of long rigid leaves, the long roots being chiefly developed where the leaf-tufts come up; its leaves roll up when the air is dry Along with these grasses, and farther inland, come the Sand Sedge (*Carex arenaria*, like the Sedge shown in Fig 76, except that its rhizome burrows deeply in the sand, running in straight lines and sending up shoots bearing tufted leaves, which are therefore arranged in lines along the surface of the sand) and other plants, whose creeping stems and tufted roots bind the shifting sand and thus prepare firmer soil for other plants. Farther from the sea come such plants as Rest-harrow (*Ononis*), Bird's-foot Trefoil (*Lotus*), Bird's-foot (*Ornithopus*), Thyme, Stork's-bill, Stonecrop, Ling, Heather, etc

628. Salt-Marshes or mud-flats occur chiefly near the mouth of a stream, usually not far from sand-dunes, and are most extensive in the tidal estuary of a river. The vegetation of a salt-marsh is quite distinct from that of sand-dunes, though a few plants occur in both sand and mud—*e.g* Sea-milkwort, Sea-plantains, Thrift, Scurvy-grass, *Suaeda, Salsola.* One of the most typical plants of salt-marshes is the Marsh Samphire or Glasswort (*Salicornia*), which has green or reddish cylindrical and fleshy branches, divided into joints, the leaves being represented only by small teeth at the joints, where also the very small flowers are produced In the wettest parts of the salt-marsh, which are submerged at high tide, we find, along with Salicornia, a Monocotyledon called *Zostera*, with long narrow floating leaves. Farther inland, out of reach of most tides, occur such plants as Sea-lavender (*Statice*, with woody creepy rhizome, "radical" lanceolate leaves, purple flowers in dense corymbose inflorescence), Thrift, Sea-milkwort, Sea-plantain, Sea Arrow-grass (*Triglochin maritimum*, with long narrow fleshy leaves, long flowering shoot, leafless, and ending in a raceme of yellow-green flowers), Salt Spurrey (*Spergular* belonging to Caryophyllaceae, narrow fleshy leaves wi scaly stipules, flowers pink), Sea-daisy (*Aster Tripoliu* like the Michaelmas Daisy of gardens, but with fleshy leave Golden Samphire (*Inula crithmoides*, a composite, with stout and rarely branched stem, 6 ins. to 18 ins. lo

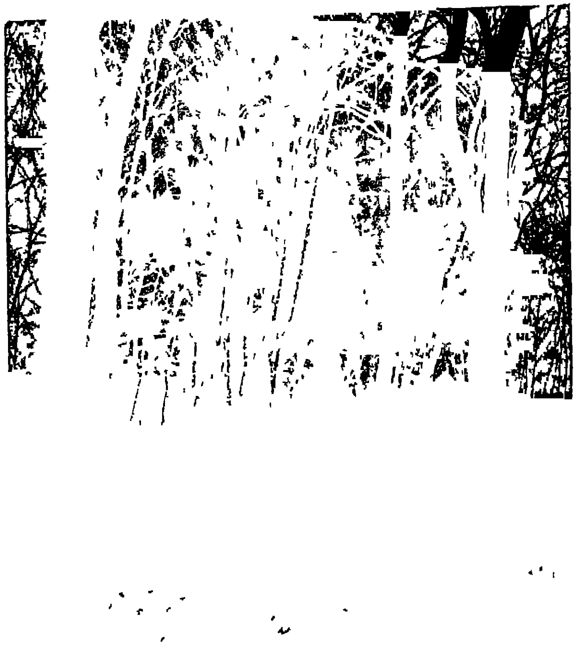

Fig 175 —A light mixed wood (chiefly Birch), showing dense undergrowth Bramble, etc

covered with narrow entire or slightly lobed fleshy lea flower-heads yellow, in a small corymb).

Look for all these plants in their homes or "habita and note any others that occur along with them. No especially the conditions under which plants live in strea ponds, marshes, bogs, heaths, chalk downs or limestone hills, sandy soils inland, and on rocky, sandy, and muddy shores, and the various ways in which the plants you find in such localities are adapted to their surroundings Sketch the plants, find out the orders they belong to and their specific names, and make sections of the vegetative parts (stems and leaves especially) to see how they differ in

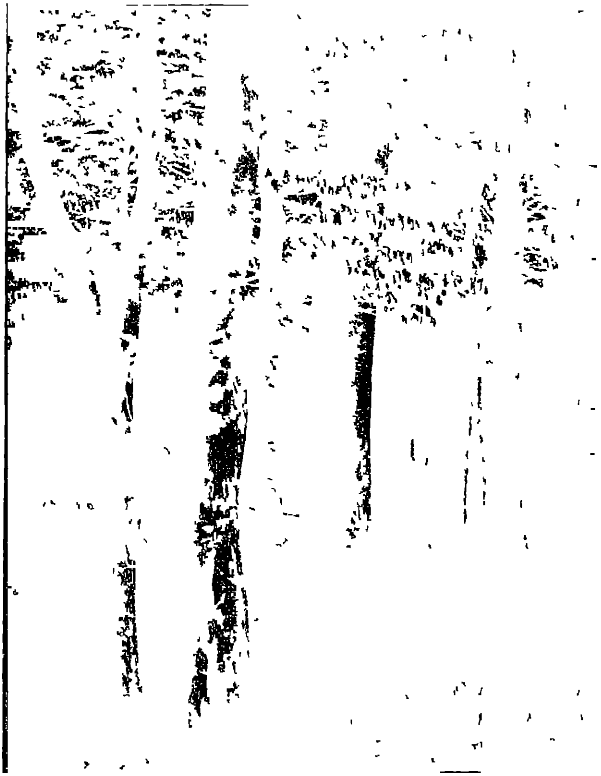

Fig. 176 —Beech wood with scanty undergrowth

structure according to the conditions and surroundings in which they grow Try experiments which may make you understand better how plants become adapted to special conditions of life For example, dig up plants found on the coast, and compare the effect of watering these plants and ordinary herbaceous garden-plants with a solution of common salt or of Tidman's Sea Salt (about a handful to two quarts of water)

Even if you cannot visit the coast or the moors, there is ample scope for study in woods and plantations, hedges and ditches, streams, ponds, and marshes.

629. Woods and Plantations.—In your study of woods and plantations, notice, in addition to the trees, the undergrowth of Shrubs, Brambles, Bracken-fern, and of smaller plants, and, in regard to the latter, find out the order in which the different plants spring up and flower. The same ground, in a wood not too densely shaded by the trees, bears at different times of the year such plants as Wood Anemone, Blue-bell (Wild Hyacinth), Dog's Mercury, Wood Spurge, Primroses, etc Many of these woodland plants only grow in shaded places—*e g.* Wood-sorrel, Cow-wheat, Bird's-nest Orchid, Yellow Dead-nettle Compare the dense undergrowth of a light Birch or Oak wood (Fig. 175) with that of a dense Beech wood (Fig. 176)

630. Hedges.—Many shade-plants grow in hedgerows, the flora of which presents several interesting features. At the top of a hedge-bank the light is very feeble and the soil dry Now all plants which grow in dry soil require plenty of light, so that the only plants which can develop at the top of the hedge-bank are either plants with long erect stems, such as the Hedge-mustard, Nettle or Thistle, or climbing plants such as Convolvulus, Hop, Clematis, Goose-grass. Lower down the hedge-bank, where there is more moisture and light, a great variety of plants may develop, while in the shady ditch beneath we may find at the sides Cuckoo-pint (*Arum maculatum*), Ladies'-smock (*Cardamine pratensis*), etc, and in the water of the ditch, the Water-buttercup, Water-cress, Duckweed, and other aquatic or amphibious plants.

Certain plants such as Poppies and Sun Spurges cannot survive under a shady hedge Others such as the Garlic, Adoxa, Violet, grow well by fairly damp hedgerows Others again, such as *Erodium*, *Geranium*, etc, will grow well on the sides of dry hedgerows provided they are freely exposed to light

The hedge itself most commonly consists of Hawthorn, but often of Gorse, Bramble, Sloe, or of small trees like Willow, or Hazel. These have usually been planted, as have, of course, the hedges consisting of shrubs like Laurels, Privets, Rhododendron, etc, around parks and plantations Why do hedges need to be pruned or "cut back," and what is the effect of this operation? Notice that plants like Dead-nettles, Yellow Toadflax, Campions, Stitchwort, when growing close to the hawthorn (or other shrub forming the hedge) push up between the branches and have long weak stems, although the same species, when growing some distance from the hedge, has short erect stems with closely arranged leaves Cases like these suggest the way in which plants, originally erect and self-supporting, may have become climbers through lack of light and the presence of a suitable support

It is very interesting to compare the nature and general appearance or "habit" of the plants growing along the north and south sides of a hedge which runs east and west. The south side is, of course, warmer, drier, and receives more light, and various plants grow on this side that either do not grow at all on the north side, or are found there in smaller numbers, and showing less luxuriant growth. In the same way the trunk of a tree which is growing in an open situation (*i e* not among others in a damp wood) generally has its moister northern side covered with a green powdery Alga (*Pleurococcus*, which is so common on trunks and palings) and with various Mosses, Liverworts, and Lichens, while the drier south side is usually quite bare In a damp wood the trunks and branches of the trees are often thickly covered with these "epiphytic" plants, often also bearing Ferns (especially Polypody)

In highly cultivated countries the hedgerows form one of the most important refuges of the original wild plants which covered the country before the advent of the plough. The other chief refuges are by the sides of streams, in stony waste places, and in permanent pastures.

631. Field Observations.—It cannot be too strongly insisted upon, that outdoor observations are absolutely essential in studying the distribution of plants and their adaptations to environment. To study this branch of Botany, *i e* Plant Ecology, with success it is necessary to have a good general knowledge of British flowering-plants, which can only be acquired by collecting and identifying, as far as possible, all the plants met with At first attention may be confined to the commoner plants and to those which show well-marked adaptations to their environment, and which occur chiefly in sharply defined "plant associations," *e g.* water-plants, heath-plants, coast-plants

The student cannot do better than begin field observations on some definite and fairly uniform area (*e g.* a sea-shore; pond, marsh, river-bank, heath, common, moor, meadow, cultivated field or garden with its weeds, hedgerow, wood or plantation with its trees and undergrowth, etc) Study this area at all times of the year, identify as many of the plants as possible, and keep a careful record, with sketches, of your observations The following hints will suggest the main lines on which the inquiry should be conducted, others will occur as your field-work progresses

1 Physical and climatic features of the area under observation (*e g* chemical and physical nature of the soil, whether retentive and ill drained or porous and well drained, height above sea-level, exposure to, or shelter from, light and wind, etc.).

2 List of the most abundant plants in the area, with notes (and sketches) on the following points in each case. General habit and mode of life (whether annual, perennial, erect, creeping, climbing, xerophytic, aquatic, saprophytic, parasitic, etc), size, form, texture, etc, of leaves; structure of flowers, with special reference to mode of pollination; structure of fruits, with special reference to mode of seed-dispersal, quantity of seed produced, etc.

3 Reasons why certain species are present in the area under consideration and absent from neighbouring areas, and *vice versâ* To determine these, compare the physical features of the different areas, and try to map out the whole district into regions characterised by definite plant associations, which will, of course, be found to merge into one another at their edges

It need hardly be added that the subject of Plant Distribution cannot be mastered by merely committing to memory lists of plant-names. It must be approached in the spirit of observation and inquiry, and the problems it presents answered with reference to the student's knowledge of the Structure and Physiology of Plants.

632. Vegetation Survey Work, which has been carried out in various parts of Britain,[1] should be attempted by the student on a small scale at any rate.

Get the Geological Survey Map of your immediate neighbourhood, to learn the characters of the underlying rock, and the sheets of the "six-inch" Ordnance Survey for the district, giving the heights, etc.

Visit the area at intervals throughout the year and make lists of the plants found The various Plant-Formations and Plant-Associations can be shown on the "six-inch" map by means of letters, numbers, signs, or lines, or by colouring with pencils or water-colours.

The smaller plant-communities are called **associations**, while **formations** are larger units each consisting of a group of associations

While these terms cannot always be sharply defined, Dr W G. Smith[2] gives the following illustration —

"A natural wood consisting entirely of oak-trees has one dominant form—the oak—whose presence is determined by the prevalent climatic, soil, and other conditions, while its size and gregarious nature give it dominance; in this wood there may be other sub-dominant trees or shrubs (*e.g* birch or hazel), more or less isolated, but which, given the opportunity by removal of the oak, will become dominant forms; the motley carpet of the oak-wood is made up of many species dependent on the larger forms for shelter and shade, or living as epiphytes, parasites, and humus saprophytes, and including not only flowering plants, but ferns, mosses, lichens, and fungi. The vegetation of the oak-wood is thus a mixed community with complex relationships, its members struggling for existence and dominance, but it is a coheren whole and may be studied as a unit or *Formation.*

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[1] See papers by Smith, Moss, Rankin, Lewis, and others, in various periodicals (*Geographical Journal*, *New Phytologist*, *Naturalist*, etc.).

[2] *New Phytologist*, 1905.

"Within the limits of a formation, there exist smalle societies, each one with dominant, subdominant, and dependent species of its own Thus the undergrowth of a

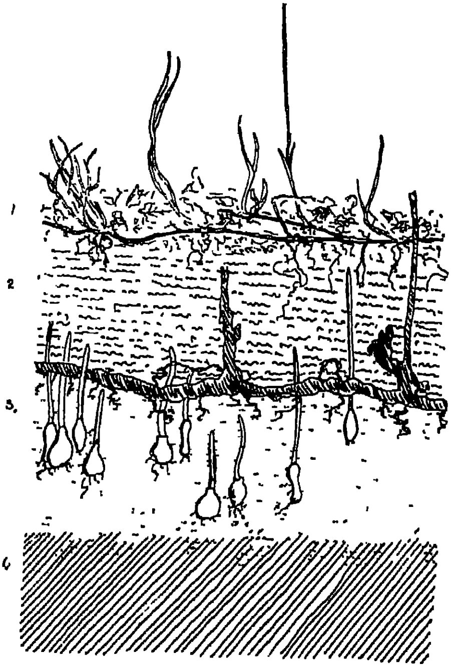

Fig 177 —Section of Soil, showing how Yorkshire Fog Grass, Bracken, and Bluebell live together, their underground parts being at different depths.

oak-wood may consist of a *Pteris-Scilla-Holcus* Association, in which Bracken, Bluebell, and Yorkshire Fog together cover a large area (Fig. 177), again it may be a *Calluna-Vaccinium* [Heather and Bilberry] Association, or one of several others"

Dr Smith gives the following specimen list of plants in a survey —

"Larch-wood, with a few Spruces, trees about 70 feet high and from 6 to 10 feet apart, two distinct associations found—*Calluna* and Bracken, the latter in hollows, the former occupying the larger, more level floor of the wood. Soil—thin peaty humus, overlying Liassic Limestone, 650 feet alt., Clevelands, W. Yorks.

Calluna Association

Social species·

Dominant,	*Calluna vulgaris*	40-50°/o	about 70°/o[1]
	Erica cinerea	20-30°/o	
Sub-dominant,	*Vaccinium myrtillus*	5-10°/o	
	Festaca ovina		about 30°/o[1]
	Aira flexuosa		
	Agrostis vulgaris		
	Anthoxanthum		

Isolated species

Characteristic.—*Potentilla tormentilla, Galium saxatile, Oxalis acetosella*, etc., in decreasing abundance

Sporadic· *Carduus arvensis* (from farm-land)."

633. Zones of Vegetation in Ponds.—The following is a description by Dr. Smith of a series of ponds at Filey, Yorkshire —

"This pond (Fig. 178) was filled with vegetation. At the southern end an inflow is shown, which was bringing in water when we saw it. From the appearance of the channel, it does not always contain water, and only acts as an overflow to some other pond in the same trough. At the northern end there is an outflow depression, which acts as an overflow channel to this pond. The water is probably derived from surface drainage, except in rainy seasons, when there will be some inflow at the southern end, and the pond will attain its maximum depth when the water begins to pass through the overflow.

The plants are arranged in four well-marked zones. (*a*) a marginal zone of taller species of Rushes (*Juncus*), (*b*) a zone of Water Dropwort (*Oeanthe fistulosa*), mixed with Water Plantain (*Alisma Plantago*) at the southern end, (*c*) a zone of Bur-reed (*Sparganium*) also mixed with Water Plantain; (*d*) a central patch of Pondweed (*Potamogeton natans*)

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[1] These percentages are estimated by eye according to the proportion of ground in a small sample area covered by the different forms of vegetation.

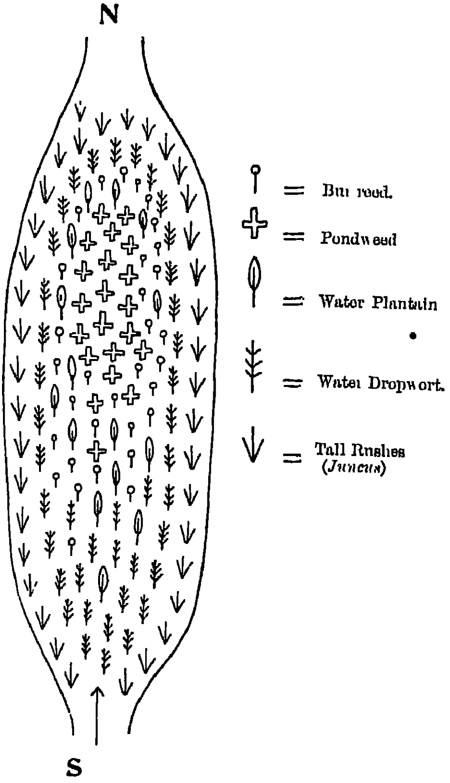

Fig 178.—*Zones of Vegetation in a Pond*

The Pondweed lies in the centre towards the northern end, its leaves were large, and with long leaf-stalks, such as occur in deep water. From this we suspect that the Pondweed occupies the deepest part of the pond. In consequence of the excentric position of the Pondweed, the zones of Bur-reed and Dropwort are narrow at the northern end, but they are sharply defined. Towards the southern end both plants lose their zonal arrangement, and form masses extending across the pond The Dropwort, however, is always nearer the shore than the Bur-reed It may, therefore, be inferred that the Bur-reed prefers deeper water than the Dropwort

The Water Plantain does not form masses like the other plants, but occurs singly amongst the Dropwort and the Bur-reed, it is not a social species, whereas the other plants shown are social It is a feature of social species of plants that they can grow closely together as a mass, and hold their own more or less completely against all comers One can appreciate this in the case of the Pondweed, with its broad floating leaves lying edge to edge, or overlapping, so as to occupy the whole surface and shade the bottom, thus checking the growth of other plants which may try to grow below them Amongst trees, the Beech is one of the best examples of this kind of social plant.

The Dropwort, Bur-reed, and Rushes are also social plants, and it is noteworthy that their long, slender, erect leaves are similar in form to the Grasses which on land are amongst the most successful of our social plants Just as the Grasses, with their closely interwoven roots and stems underground, and their close, erect, leafy shoots above ground, can keep in check the growth of other plants and maintain a close sward, so in our pond the Dropwort, Bur-reed, and Rushes maintain themselves in distinct zones with little mixture. The Dropwort is not quite so successful as the other two, and amongst it plants of Water Plantain have found a place and have also succeeded in gaining ground in the closer Bur-reed zone.

Turning now to the Rushes on the margin The Rushes form a close well-marked zone, which at the time of our visit was standing in water and therefore formed part of the pond-vegetation. Out of the water there was, however, no scarcity of Rushes, and from general experience most of us would regard the Rushes as plants of the marsh rather than water-plants. The Rush zone of this pond therefore indicates that part of the margin which is only occasionally under water, and is generally marsh.

From this one may infer that this pond, as a rule, contains less water than when we saw it It has a maximum depth which is determined by the sill of the outflow channel. The ebb extends at least to the lower margin of the Rush zone, but the Dropwort, Water Plantain, and Bur-reed are all plants which may grow in a wet marsh, and it is probable that this is the drought condition of that part of the pond occupied by these plants From the appearance of the Pondweed we should say that its area is never quite free from standing water.

Fig. 179 represents what has been a pond, but is now so dry that it might be described as a dry marsh. The shape of the hollow is like that of the true ponds, and there is a distinct outflow channel. There is also an inflow channel of the kind seen in Fig. 178, namely, an occasional channel which drains the overflow from some adjacent hollow.

Near the centre are patches of two water-plants—Pondweed and Bur-reed—restricted to what are now the wettest spots. The Pondweed has small reddish leaves with short stalks, the Bur-reed has short narrow leaves, both are land-adaptations and are probably remains of the original aquatic vegetation which has been displaced.

The other conspicuous plants of the pond-hollow are (a) Water Sweet-grass (*Glyceria aquatica*), occupying the centre except the parts utilised by the Pondweed and Bur-reed; (b) *Iris pseudacorus* at the southern or inflow end; (c) Marsh Horsetail (*Equisetum palustre*) at the

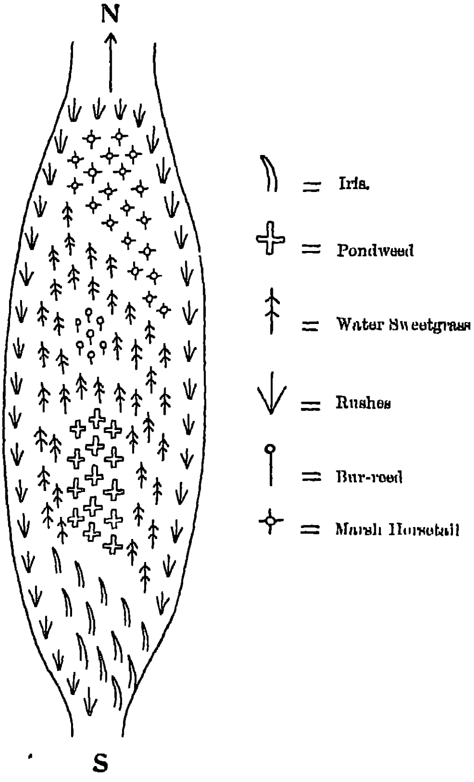

Fig 170.—"Dry" Pond

northern or outflow end, (d) a broad marginal zone of Rushes. The large patch of Water-grass indicates the part of the hollow which is occasionally under water. It is a feature of this grass that it grows well in a moist place liable to inundation The Iris and Marsh Horsetail occupy well-defined areas, and both are typical marsh plants. Altogether the vegetation of this hollow indicates that it is moist, and even marshy at times, but is never long under water.

The ponds at Filey are thus instructive examples of aquatic and marsh vegetation The ponds themselves show every stage of transition from ponds of open water to marshy hollows, and even dry hollows "

634. Weeds of Cultivated Soil.—There are many points of interest in connection with the weeds of cultivated fields and gardens For instance, the majority of these plants are annuals, and many of them are never found in a truly wild state They appear to depend upon cultivation, and many of them have a very wide distribution over the earth

You should make observations on the succession of the weeds that spring up on a field which is allowed to remain fallow, or on a piece of cleared ground. Annuals come in the first year—Charlock, Chickweed, Goosefoot, Red Dead-nettle, Fumitory, Scentless Mayweed, Shepherd's Purse, Groundsel, Spurges, Scarlet Pimpernel, etc Next year the perennials (some of which may have already got a footing) usually become abundant and aggressive—Nettles, Docks, White Dead-nettle, Thistles, Ragwort, Plantains, Daisy, Dandelion, etc , also various Grasses, *e g*. Cock's-foot, Couch-grass, and such shrubs as Brambles By the third or fourth year the ground may be chiefly occupied by perennials.

Also make observations, at different times of year, on the vegetation of **rubbish heaps, pastures, roadsides, railway-banks** (note the differences between **cuttings** and **embankments** with regard to the conditions of life and the plants found), **garden borders, lawns, ballast-hills** beside seaports, **pit-heaps** beside collieries, **waste ground** near mills, etc On rubbish-heaps and ballast-hills we often find alien plants (brought from foreign countries) along with such plants as Annual Dog's Mercury, Teasel, Docks, Ragwort, Knotgrass (*Polygonum aviculare*), Henbane (2-4 ft , leaves lobed sticky and clammy, firs with 5-lobed corolla yellow with purple streaks) Teasel and Henbane often grow in waste places by the sea, and several plants are rarely found except on rubbish-heaps or on rich waste ground beside houses or farm-buildings, *e.g.* Greater Celandine (*Chelidonium*, Poppy family), White Dead-nettle

In my fairly well tended garden-borders (area about 100 square yards) I have, during the last four years, compiled a "flora" of over 140 weeds, of which about 110 are annuals, and in a disused gravel-pit close at hand, which I have watched continually since it was abandoned four years ago, I have counted about 70 species, including several shrubs, young trees, and marsh-plants which have settled down during this time and produced a dense vegetation The garden has b manured twice during the four years, while the gravel-pit has b used as a "dump" for market-garden rubbish and street-mud, he the richer flora as compared with that seen on a larger area of wa ground hard by—a field which has been enclosed and had much of turf removed by builders for lawn-making

The vegetation of a **lawn** is often very interesting The lawn its consists of various grasses (species of *Poa*, *Alopecurus*, *Cynosur* *Festuca*, *Phleum*, etc), often mixed with white Clover, but it usua has various weeds which are well adapted to resist the lawn-mow *e.g* Daisy, Dandelion, Plantain, Hawkweeds, Thistles, Cat's-e Autumn Hawkbit, which have "radical" leaves in a rosette grow close to the soil and kept there by the contractile roots, also coa rampant Grasses, like Couch-grass which spreads by long undergrou runners A damp or ill-kept lawn has a covering of feathery Moss on the soil, and is often invaded by various weeds which can compe with the Grasses, *e.g* Buttercups and even Horsetails

QUESTIONS ON CHAPTER XXVII

1 For what different purposes do you consider that a plant requir to be supplied with water? How are some plants able to withstan long-continued drought uninjured? Give instances of such plants.

2 How does the climate inside a greenhouse differ from that witl out? Name plants whose natural habitats are in climates (*a*) drier, (wetter, (*c*) hotter, (*d*) colder than that of an English garden Wh arrangements would you make if you had to try to grow these vario plants in England?

3 The island of Singapore produces more than 2,000 native specie of flowering plants; the Isle of Wight (about equal in area) some 800 an equal area in the Egyptian Desert less than 200 To what cause would you attribute these striking differences?

4 How far do characters of the soil, other than its chemical nature determine the flora growing upon it?

5. Describe the chief modes of perennation in herbaceous plants.

6 Describe the different localities in which plants store up nutrimen in one year for their own rapid growth in the next year, and state th nature of the stored substance in the case of each plant that you cite

7. What wild flowers have you found growing along the margins o lakes, ponds, and rivers? Distinguish those which grow with their stems (*a*) wholly in the air, (*b*) partly in air and partly in water, (*c*) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin

8. Name any plants growing with their leaves wholly submerged How do such leaves differ from leaves surrounded by air?

9 Give the names of four water plants and four marsh plants Mention all the points you can think of in which water plants differ from land plants Can you give any explanation of the facts described?

10 Write a list of any plants which you have found growing with their leaves submerged in water How do such plants obtain the gases which they require for respiration and photosynthesis? Describe the surface structure of a leaf (*a*) in a land-plant, (*b*) in a water-plant

11 What special anatomical peculiarities would you expect to find in water-plants? Explain how the structure you describe is connected with their conditions of life

12 Enumerate the more common plants which you have found growing in a marsh

13 Write a list of plants which you have found on moorland walks What peculiarities of leaf-structure have you observed in any six of these? How does the possession of such peculiarities profit the plant? What was the nature of the soil on which the moorland plants grew?

14. Name all the plants you have found either on a heath or on a moor, distinguishing carefully those which you have *only* found on heaths or moors Point out any features which you think fit the plants to live in such situations

15. Mention twelve plants you have found growing in company with the Ling (*Calluna*) Describe the plants on which such plant-associations occur, and any general features of heath or moorland vegetation you have observed.

16 Write an account of the vegetation you might expect to find growing on a swampy moor, and indicate any points in which the plants appear to be structurally adapted to such an environment

17 Discuss the ecological conditions that may determine the formation of the "Heather moor," and give some account of the composition of the flora of each moor.

18. How could you distinguish between Ling, Bell Heath, Cross-leaved Heath, and Crowberry, merely from leaf-bearing branches without flowers? Describe the structure of the leaf in each of these four plants, and explain how the structure is adapted to the habitat

19 Describe the flowers of Ling, Bell Heath, and Cross-leaved Heath, pointing out their differences and explaining the pollination mechanism

20. Describe the flowers and fruits of Crowberry Compare this plant with the Ericaceous moorland plants

21 How can you explain the fact that most moorland plants, *e g* Ling, Heaths, Crowberry, are protected against free transpiration, although moors get so much moisture in the form of rain and mist?

22 Why is the vegetation of a high moor dwarfed, with no trees, while low moors (heaths) are often dotted with tall trees?

23. In what respects do many moorland plants agree with plants growing on sandy coasts and in salt marshes? How may these resemblances be explained?

24. What is the difference between a marsh and a bog?

25 Name several different species of plants that you have found at the seaside and not inland. State exactly where and how each was growing, and mention any characters possessed by each that you think fitted it to its particular circumstances

26 Give an account of the vegetation of sand-dunes in any region you may select, and point out the special adaptations exhibited by the plants to their surroundings

27 Mention six plants you have found growing (*a*) on shingle-beaches, (*b*) in salt marshes Distinguish between those occurring only in these habitats and those you have also found inland.

28. Mention eight plants that you have found growing in each of any three of the following situations —Cornfields, Freshwater Bogs, Shingle Beaches, Sandy Heaths

29 What plants would you expect to find in *any three* of the following places —(*a*) an open heath, (*b*) a salt marsh, (*c*) a Freshwater pond, (*d*) chalk downs?

30 What would you infer as to the characters of the soils in which the following plants were severally to be found growing?—Spurrey (*Spergula arvensis*), Coltsfoot, Rush (*Juncus communis*), Cotton Sedge, Wood Sage (*Teucrium*), Bee Orchid.

31 Give several examples of groups of plants which grow together in the same habitat or locality and flower at about the same season Why do these plants grow side by side, what causes bind them to special localities, and why do they flower simultaneously?

32 Mention eight plants that you have found growing on open roadsides (not much shaded by hedges), and eight that you have found growing under the trees of a wood Have you noticed any characters of these two groups which seem to you to have anything to do with the difference of habitat?

33 Show, by reference to alpine plants, to the carpet of spring flowers in woodlands, to flowers of foreign origin in English gardens, to the lack of flowers in hayfields after July, and by other illustrations, that the competition of neighbouring plants is one important condition of plant-life.

34 Name two or three shrubby plants which most commonly compose the hedges of fields, also any other shrubs you have seen growing in hedges Explain the effect of cutting a hedge on the growth of hedge shrubs.

35 Name the month or months of flowering of each of the following plants Alder, Ash, Beech, Bluebell (Wild Hyacinth), Coltsfoot, Elder, Gorse, Hazel, Honeysuckle, Horse-chestnut, Ivy, Laurustinus, Lesser Calandine, Ling, Oak, Pine, Ragwort, Red Campion, Snowdrop, Sweet Chestnut, Tormentil, Water-buttercup, Water-mint, Wood-anemone, Wood-sorrel.

36 Give an account of any observations you may have made on the colonisation by plants of land bare of vegetation. What characters enable plants to colonise such land?

37 To what extent has the natural wild vegetation of this country been modified or destroyed by mankind or by domestic animals? Describe ony piece of ground that appears to you to represent primitive nature untouched by the hand of man.

38 Explain how it is that Dandelions and Plantains are able to live so successfully as weeds in a lawn

39. What other plants have you found growing among the grass of a garden lawn? Explain why these plants are able to grow there, and show how the garden-mowing machine or scythe and other causes select or influence the flora of the lawn

40. Mention the six most troublesome weeds in any garden with which you are well acquainted. Explain carefully, so far as you can, the reasons why each is specially troublesome.

41. Mention any observations you may have made on the flora of ground that has been turned over but not planted—*e g* railway embankments, fallow fields, garden beds Can you give a list of plants growing in such places, and account for their presence?

42. Describe the vegetation of an Oak *or* Sycamore wood, naming the plants observed and the dates of flowering Compare the vegetation with that of a Beech wood How do you account for the difference?

43 Suppose you were asked to write a report on the vegetation of some particular acre of ground (heath, common, meadow, marsh, woodland, moor, or hillside), how would you set about the task? What would you try particularly to find out? What observations and notes would you make? How much time would you wish to be allowed for the inquiry?

CHAPTER XXVIII.

THE USES OF PLANTS.

635. Vegetable products not only supply us, directly or indirectly, with all our food except water and salt, but furnish us with much of our clothing, medicine, furniture, and many other necessities and luxuries of life

Vegetable Technology or **Economic Botany** is a most important branch of botanical science, which can only be dealt with here in a very fragmentary manner Further details will be found in such books as Freeman and Chandler's *Commercial Products* (Pitman and Sons), and the Official Guides to the Museums of Economic Botany at Kew Gardens and the Imperial Institute, both of which should be visited by the student

Apart from wood, cork, and fibres, most economically useful plants are useful because they contain substances formed as reserve stores of food or as bye-products and excretions, though most green vegetables and salads contain little more than the ordinary substances found in plant-tissues In forming reserves (in fruits, seeds, rhizomes, bulbs, corms, tubers, roots, etc) the plant always stores both nitrogenous and non-nitrogenous materials, the former chiefly as proteids, the latter as starch, cellulose, inulin, oils The waste-products (some, however, capable of being used up again in the plant's nutrition) include oils, wax, resin, alkaloids, latex, etc , which are practically always stored within the cells or in special cavities or passages

Medicinal products and forage-plants are not dealt with here Apart from these we might classify useful plants into those yielding food-stuffs and those used for other purposes, or we might arrange them in their families according to the modern system of classification. The latter plan, often followed, has many advantages , for one thing, many families are distinguished by yielding similar economic products, e.g. the cereal Grasses, the acrid Ranunculaceae, the pungent but harmless Crucifers, the aromatic pot-herb Labiates, the resinous Conifers, and so on. But in a short account like this it will serve to adopt the simpler plan of noting which plants and parts of plants supply various materials commonly used.

636. Wood.—Monocotyledons do not yield much useful timber, owing to the scattered bundles and the usual absence of secondary thickening, though whole and split stems of Bamboos, Palms, etc., are largely used.

The most generally useful plants yielding timber which can be sawn up are the Conifers, their wood being usually soft enough to be easily worked, the stems straight and regular, while the resin they contain prevents decay.

The chief timbers we import are Scots Pine ("Red and Yellow Deal"), mostly from the Baltic ports (the finer kinds from Russia and Sweden), Spruces (*Picea*), from Baltic, Canada, etc., and various others in smaller quantity. Larch, Oak, Beech, and a few others are largely grown in Britain, but this country, by far the largest importer of timber, has only about 3 million acres of forest (4 per cent. of the total area, a lower percentage than in any other state except Portugal); we import timber annually of value 30 millions sterling.

Apart from shipbuilding, the woods used for piles and other submerged structures (locks, water-wheels, etc.) are Elm, Larch, Chestnut, for bridges, piers, and other constructions requiring great strength and resistance to strains, Oak and the harder kinds of Pine, for railway sleepers, which must be durable in contact with earth and metal, creosoted "Red Deal" (Scots Pine), for pit props, Larch and Scots Pine, also Cluster Pine from S. France for Welsh collieries, for telegraph poles (requiring, like ship-masts, elasticity and wind-resistance) Pines and Larches, for scaffold-poles and ladders, Spruce, for rafters and flooring, Scots Pine from Dantzic, and the cheaper Norway variety imported as ready-made flooring, also American Pitch Pine, Larch, Black Spruce, for wood-paving both cheap soft wood (Pine) and more durable hard wood (Eucalyptus), for fencing, chiefly Oak, Larch, Chestnut, for general carpentry needing cheap, easily-worked, and fairly durable wood, Pine, also Spruce, Oak, Ash, etc., for carriage-building, tough hard woods not liable to splinter (Hornbeam and Elm for hubs, Oak, Ash, Robinia, etc., for spokes—Hickory for axle-trees and shafts—Poplar, Birch, Maple, etc., for panels—Willow for wheelbarrows), and so on.

In furniture-making (needing beauty of colour or grain, durability, susceptibility to polish) an immense variety of woods, Oak was the chief furniture wood until modern times, and it is interesting to note the various woods used at different periods for furniture, carving, etc. (as seen in the South Kensington Museums); e.g. Gibbons used Lime and other soft white woods for his marvellous carving, while Mahogany has been greatly used for furniture since the times of Chippendale, Hepplewhite, and Sheraton, as have Walnut, Birch, Hazel (often sold as Oak), Pine ("deal," in cheap goods), American or Canary Whitewood (Tulip Tree) for chair-seats, Beech and Yew by the Bucks chair-makers, Ash chiefly for bent woodwork, and so on.

The turner, who needs close-grained woods not too easily splintered and capable, if necessary, of taking polish, uses largely Ash (cankered and twisted wood is best for mallets), Beech for wedges, planes, tool-handles, Pear for T-squares, Elm for Bowls, Walnut for gun-stocks, etc

For walking-sticks, many British trees, also canes (Bamboos), leaf-stalks of Date Palm, and Cabbage-stems (Jersey Cabbage), for wood-engraving (now largely superseded by metal-blocks) Box is unequalled, but Hawthorn, Pear, and Dogwood are also used, Box getting scarce; for piano sounding-boards, Spruce, the most resonant wood; for tobacco-pipes, "Briar" (a species of *Erica* from S. Europe); for pencils, Cedar from Bermuda and Virginia, for toys, soft white woods like Willow, Alder, Poplar, Lime, Pines, etc, for packing-cases, Norway Spruce and Silver Fir, both cheap

637. You should study (1) the general structure of woody stems (Arts 295-304), noting especially the process of secondary thickening, cambium, annual rings, rays, bark, (2) the texture and other distinctive features of different woods, including such defects as "shakes" of various kinds, knots, burrs, etc; (3) diseases of timber, how caused and how prevented, (4) the reasons why different woods are selected for different purposes, *e g* turnery, shipbuilding, cabinet-making, (5) the sources of different timbers, imported and British-grown You can get specimen-blocks of different woods from timber-merchants or joiners, some cut to show the transverse, radial, and tangential surfaces, others with the bark left on, thin broad slices, suitable for examination with lens, or low power of microscope, can be obtained from dealers in educational supplies.

Try the various reactions of lignified (woody) cell-walls —coloured yellow with iodine or chlor-zinc-iodine, coloured yellow and swollen with iodine and sulphuric acid, coloured bright yellow with acidulated solution of aniline sulphate, chloride, or nitrate, red with acid solution of phloroglucin; green on exposure to light after treating with mixture of carbolic and hydrochloric acids (test for coniferin); not stained, or but slightly, by carmine and haematoxylin solutions, but deeply stained by aniline dyes.

638. Cork is almost solely obtained from the Cork Oak of S. Europe, and (despite its extreme lightness) several thousand tons are imported yearly (mostly from Spain); the "virgin cork," which is rough and furrowed, is the first crop taken from young trees (10-15 years old), and is used for window-boxes, ferneries, etc. The ordinary "bottle-cork" is cut off every 10 or 12 years, care being taken not to cut too deeply as to injure the cork-cambium.

If done with care, the removal of the cork seems to benefit rather than injure the tree. It is removed by longitudinal and transverse cuts, or by a cork-cutting machine, in slabs weighing about 40 lbs., steeped in boiling water or steamed to increase its elasticity and remove tannin and other substances, then scraped, cut to the required shape, washed in oxalic acid, and dried. The lightness of cork is due to the air enclosed in its cells, which have thin but tough cell-walls.

Examine (1) pieces of rough cork, as sold for window-boxes, etc.; (2) cut cork, *e.g.* bottle-corks, noting the thin dark layers here and there, and the lenticels (canals filled with loose powdery cork-cells); note how bottle-corks are cut so as to avoid having lenticels running *longitudinally* in the cork when fitted into the bottle-neck.

Cut thin sections from a bottle-cork, soak in alcohol (to remove air-bubbles), then in water, mount in glycerine, and with low power of microscope note the regular arrangement of the cells in rows, the thin pale yellow or brownish cell-walls, and the absence of cell-contents.

With iodine, corky cell-walls turn deep yellow; with iodine and sulphuric acid they turn deep yellow or brown, but do not swell (compare with woody walls); with strong potash they turn deep yellow and on heating yellow drops of suberin (corky substance) escape; with stains (carmine, haematoxylin, aniline dyes) they behave like lignified walls; heated with Schulze's macerating fluid (chlorate of potash in nitric acid) they lose their outline and run into drops (of ceric acid). All these reactions can be done with slices of cork on a glass slip, but be careful not to let acid or acid fumes get on the microscope.

639. Fibres, used for cordage, mats, weaving, etc., are mostly (1) the lignified sclerenchyma fibres in stems of herbaceous Dicotyledons and (2) the entire bundles of Monocotyledonous stems and leaves.

In the former case the "bast"-fibres (usually in strands outside of the phloem of the vascular bundles) are obtained by soaking the stems in water and beating the fibres out; the chief fibres of this kind are Flax (grown largely in

Ireland, but about half our supply imported from Russia) from *Linum usitatissimum*, Hemp (*Cannabis*, Nettle family), Jute (*Corchorus*, Tiliaceae), Sunn Hemp (*Crotalaria*, Leguminosae), Rhea or Ramie (*Boehmeria*, Nettle family) The inner bast of Lime-tree is also used, but the wood-fibres and vessels of stems are shorter and less useful than the bast-fibres, which are alone used for weaving

The chief Monocotyledonous fibres obtained from the leaves, by maceration and beating, are Manila Hemp (*Musa*), Sisal Hemp (*Agave*), New Zealand Flax (*Phormium*), Bowstring Hemp (*Sansevieria*), Mauritius Hemp (*Furcraea*). The entire leaves of various Grasses, *e g.* Esparto-grass (*Stipa*), and Sedges (*Cyperus*) are used for making paper, mats, etc , similar use is made of the straw of Cereals, Rush-stems, Osier-twigs, etc Many Palms have fibres on their leaf-bases and fruits, used chiefly for brushes and other coarse work, but in some cases for cordage, *e g* Coir (Coco-nut)

640. Cotton.—By far the most important surface-fibres, however, are those of Cotton (*Gossypium*, Malvaceae), the fibres being long unicellular hairs on the seeds (for wind-dispersal) inside the capsule These hairs, sometimes over 2 ins long, each forming a flat twisted tube, wider at the middle than at its origin from the epidermis and at its free end, when mature the flattened cavity contains practically only air

Moisten some "cotton-wool" with alcohol, then soak in water, and examine with the microscope, noting the long unbranched unicellular hairs, the thick colourless cell-wall, and the remains of granular protoplasm (sometimes this has entirely disappeared) Soak some in iodine and note the walls stained yellowish Mount some of the iodine-soaked cotton in a drop of sulphuric acid , note that the walls become blue and swell up considerably, while the hairs become untwisted; in cotton treated with chlor-zinc-iodine, the wall stains blue or violet, while the remains of the protoplasm (if present) stain yellow; with aniline sulphate the walls are not stained, since they consist of cellulose and are not lignified

Dissolve some copper sulphate in water, add dilute potash, collect the precipitate on a filter and dissolve it in ammonia , place some cotton-wool in the solution thus obtained, and note that it swells up, the hairs fusing into a jelly-like mass and finally dissolving (a characteristic reaction of cellulose)

641. Paper-Making.—Many vegetable fibres have been used for paper, besides such substances as rag, straw, peat, and Bracken, but they are now largely superseded by wood-pulp, so much of which is used that the world's timber-supply is being seriously affected The best woods are Poplars, Alder, and Spruce, while Pine wood is used for coarser sorts of printing-paper, packing-paper, and card-board

642. Dyeing Materials.—Organic Chemistry has largely superseded natural dyes by artificial synthesis and the preparation of the endless aniline series from coal-tar Most natural vegetable dyes are obtained by soaking the plant in water. The synthesis of alizarin in 1869 almost destroyed the cultivation of Madder (*Rubia*) ; that of artificial Indigo will probably in time stop the growing of the Indigo-plant (*Indigofera*, used to make laundry blue as well as for dyeing), which itself superseded woad (*Isatis*)

Plants still used are Logwood (*Haematoxylon*), Fustic (yellow, from wood of *Maclura*, Mulberry family, West Indies) ; Turmeric, now used more as curry powder than a dye , Arnalto is the red pulpy seed-coat of a S American species of *Bixa*, used to dye silk orange or yellow and to stain Dutch cheeses ; Saffron, the stigmas of *Crocus sativus*, is used chiefly to colour cakes, not being a permanent dye Alkanet root is used as a red dye for imitation rosewood furniture.

643. Tanning Materials of plant origin have, like vegetable dyes, been largely replaced by chemicals, *e g* in the chrome-process, but many are still used Tannins are probably useful in the nutrition processes of plants, since they often occur in growing parts, but when they occur in such parts as the bark they can only be regarded as excretions, having a secondary use in protecting the plant against animals, etc

The chief natural tanning substances are obtained from Oak (bark, acorns, galls), Sumac (twigs and leaves), Acacia, Birch, Hemlock Spruce, Eucalyptus, etc Tannin occurs both in cell-sap and cell-walls , it is coloured deep-brown by potassium dichromate or chromic acid, greenish blue by ferrous sulphate dissolved in nitric acid, and gives a yellow precipitate with solution of ammonium molybdate in ammonium chloride.

644. Oils may be, for general purposes, divided into (1) fixed oils, found chiefly as reserve food in seeds and usually obtained by pressure, (2) fats, (3) waxes, (4) volatile oils obtained from leaves, flowers, etc., by distillation

Fixed oils include non-drying oils (remaining fluid except at very low temperatures), *e g* Almond, Brazil-nut, Castor, Colza, Cotton, Mustard, from seeds, Olive from flesh of drupe, and drying oils, used in painting, etc, *e g* Linseed (Flax seeds), Sunflower, Walnut

Fats, remaining solid at fairly high temperatures, include Cocoa-nut or Copra (endosperm of *Cocos*), Palm-oil (mesocarp of *Elaeis*), Cacao-butter (fruit of *Theobroma,* the Cocoa-plant), and still firmer substances used as butter or grease and obtained chiefly from Palms

Vegetable waxes are not much used except Japanese Wax from Laquer-trees (*Rhus* species).

Volatile oils are distilled from the leaves of various Labiates (Lavender, Mint, Peppermint, Patchouli, etc), Eucalyptus, Orange and its allies (Lemon, Bergamont), Cinnamon, Rose, Clove, some Grasses (Lemon-grass *Andropogon*), etc

Oils are stained black with osmic acid and red with alkanna, soluble in ether, and saponified (converted into soap) with potash (try these tests on a section of Almond, Brazil-nut, and other seeds), ethereal oils are dissolved by alcohol, fixed oils (except Castor-oil) are not

645. Gums, formed by disintegration of the internal tissues (chiefly of the cell-walls), are yielded by many plants, especially by those growing in dry countries Gummy cell-walls (cut sections, with razor dry or wetted with alcohol, of dry Linseed, mounting in pure glycerine) swell with water (and to a greater extent with potash), are unstained by iodine (but sometimes stain blue with iodine and sulphuric acid), and stain pink with corallin-soda, gum formed from *protoplasm* may be seen in sections of tubers of Early Purple Orchis

Gums are insoluble in alcohol, but most dissolve in water, arabin completely, bassorin slightly, while cerasin is insoluble, these three types of gum occur in *Acacia* (Arabic, Wattle), *Astragalus* (tragacanth), and Cherry respectively.

646. Resins, produced by secretion or disintegration and contained in special passages or cavities, are typically yellow transparent substances insoluble in water but soluble in alcohol, ether, etc., and may be divided into true solid resins, gum-resins (mixtures of gums and resins), and balsams (fluid resins and resins dissolved in ethereal oils).

The chief **balsams** are those of Conifers (turpentine), when distilled, resin is left and oil of turpentine passes over. Other balsams are Tolu (*Toluifera*), Storax (*Liquidambar*), Benzoin (*Styrax*), Copaiba (*Copaifera*), etc.

The chief gum-resins are Gamboge (*Garcinia*), Frankincense (*Boswellia*), Ammoniacum (*Dorema*), Asafoetida (*Ferula*), etc.

The **true resins** include common resin or "rosin," distilled from turpentine of Conifers and used in making varnishes, which are simply solutions of resin in oil of turpentine (common "turps") or alcohol, also the copals and dammars Many resins are also used in medicine and laquer-work

Kinos (from *Eucalyptus*, etc), used in medicine and tanning, are resin-like in appearance, but soluble in water **Camphor** is also resin-like but crystalline, various kinds are distilled from leaves of Camphor, Cinnamon, etc.

647. Rubbers are obtained from the juice (latex, often milky) of tropical trees, in which it exists as suspended particles, these clot, on the escape of the latex, after cutting the bark, either by drying or by use of acetic acid, etc. The chief rubbers are Para, Panama, Ceara, African, etc., from plants belonging to the Spurge, Periwinkle, Fig, and other families Rubbers are usually "vulcanised" by treatment with sulphur, to make them more durable, they are soluble in chloroform and benzol, swollen by potash but not dissolved, and stained with alkanna.

In Dandelion, and other Composites with ligulate flowers only, latex is secreted in a network of vessels formed by cell-fusions in different directions; cut tangential sections from bast of root and note the long parallel vessels with horizontal cross-connections In Spurges it is contained in branching tubes which are not joined up, and in it are curious dumb-bell-shaped starch-grains, also proteid-masses.

648. Starches.—Besides its use in food and breadmakin starch is largely used in calico-printing, as toilet powder, an for making paste, dextrin, and glucose.

Starch was until 1840 chiefly made from Wheat-grains b steeping and fermenting to remove the other constituent but is now made from Potatoes and Rice. Dextrin, used i "dressing" muslin, etc., for postage stamps and envelope and other purposes, is made chiefly from Potato starch b heating or treatment with dilute acid, while glucose is mac from Potatoes, Maize, Wood, etc., by carrying the dextri process further.

The chief edible starches are Arrowroots, Sagos, Tapiocas, an various preparations (*e g.* "breakfast-foods") of Wheat, Barley, Oa and Rice Meal.

Arrowroot comes from the rhizomes of various plants (*Marant Canna*, *Curcuma*, *Manihot*, etc.), in tropical and sub-tropical regio (West Indies, Brazil, Natal, East Indies), **tapioca,** from the tube of species of *Manihot* (Spurge family) in S. America, etc., differs in havin undergone partial change into dextrin by being dried on hot plat instead of in the sun; **sago,** from stems of Palms in Malay, S. Americ etc., Maize starch gives **corn-flour**, **semolina** is made from har "flinty" varieties of Italian Wheat.

Buckwheat (*Fagopyrum*, Dock family) is made into mea like the true cereals (Wheat, Oats, Barley, Rye, Mille Rice), besides being used (like Maize) for poultry food **macaroni** and **vermicelli** are prepared from hard an highly nitrogenous varieties of Italian Wheat.

649. Sugars are chiefly obtained from Cane, Maple, Bee Palms, and starch. The "canes" of *Saccharum* are crushe and yield crystalline, raw or brown sugar and uncrystallise molasses, the latter being distilled to make rum, while th former is refined for loaf-sugar, treacle, and syrup. Mapl sugar is the spring sap of several N. American Maples, bu most of it is used in U. S. A. and Canada and little exported.

Beet sugar, the manufacture of which began in Franc under Napoleon I. and is subsidised by various Europea states, competes seriously with cane sugar and will probabl become the chief supply, the sugar beet can easily be grow in England, and 100 lbs. of roots yield about 7 lbs. suga Palm sugar, mostly obtained from Date Palm by cutting th spadix and collecting the juice ("toddy"), is chiefly consumed on the spot (India), but also sent to England as cane sugar

We consume over a million tons of sugar annually, about 70 lbs. per head of our population.

650. Pulse comprises the seeds of Leguminous plants, rich in proteids, *e g* Peas, French Bean, Broad Bean, Lentils, pods of Runner Bean (ripe seeds unwholesome), French Bean (ripe seeds = Haricots), and the underground fruits of Earth-nut (*Arachis*, also called Pea-nut and Monkey-nut) which are very oily (oil used for soap, candles, cold cream, etc.)

651. "Roots" and **"Tubers"** are more watery vegetables, including Potato, Sweet Potato (*Ipomaea*) and Yams (*Dioscorea*) being its tropical substitutes; Jerusalem Artichoke (no starch, but rich in sugar and inulin), Turnip (no starch or sugar, but a pungent essential oil), Carrot (4-5 per cent sugar), Parsnip (both sugar and starch), Beet-root (10 per cent sugar); Onion (essential oil and some sugar), Salsify and *Scorzonera* have edible roots

652. Green Vegetables include various plants whose leaves, buds, inflorescences, etc, are eaten, usually cooked, *e g* the various forms of Cabbage (Art 380), Spinach (several Chenopodiaceae with leaves rich in nitrate of potash, species of *Spinacia*, *Atriplex*, etc), Beet (leaves of small varieties), Seakale (blanched stems and leaf-stalks), Celery and Cardoon (blanched leaf-stalks), Asparagus (young annual shoots), Globe Artichoke (receptacle and fleshy bases of bracts), Leeks, young shoots of Nettle and Hop

Salad-plants, usually rich in potash, salts, and eaten raw, include Lettuce (slightly narcotic), Water-cress (rich in sulphur), Cress and Mustard (young seedlings eaten), Endive and Dandelion (leaves blanched), Sorrel.

The chief fruits eaten as "vegetables" are various Bean-pods, Tomato, Marrow, Cucumber (young fruits pickled as "gherkins")

653. Fruits.—Apples, Pears, Service, Quince, and Medlar are the chief pome-fruits, Plums (including the varieties Damson, Greengage, dried "prunes," etc.), Cherries, Apricot, Peach, and Nectarine (smooth-skinned variety of Peach) a the chief drupes (Almonds are also drupes, with edible *seed* not fleshy mesocarp), Grapes, with several varieties, e Raisins (dried grapes), Currants (dried small seedles grapes), Oranges, Lemons, Citron, Grape-fruit, Lime-fru (berries with ovary-chambers filled with fleshy hairs); Dat (1-seeded berry), Pomegranate (2 tiers of carpels, seed-coat fleshy), Banana (fairly rich in nitrogenous matter as well a in sugar and jelly), a seedless 3-chambered inferior berr (note remains of perianth, etc, at free end), Water Melon (structure as in Marrow and Cucumber), Strawberry Blackberry (Bramble), Raspberry, Gooseberry, Currant (Black, Red, White), Elder, Mulberry, Fig, Pineapple Cranberries (imported from Russia and U S A.), etc

654. "**Nuts**," rich in proteids and fixed oils, includ Hazel (Filbert, Cob, Barcelona-nuts), Walnut, Brazil-nut (seeds, about 20 formed in each fruit), Sweet Chestnut (littl oil but much starch), Coco-nut (a drupe), Pistachio, etc.

655. "**Food Adjuncts**" are (1) alcoholic liquids, (2 condiments, (3) flavouring substances, (4) alkaloids

(1) **Alcohol** is obtained chiefly by distilling fermented sugary liquids Beer is made by allowing grains (Barley Rye, etc) to germinate, the endosperm-starch becoming converted into sugar, then stopping the diastase-action by heat adding Yeast to convert the sugar into alcohol (carbon dioxide and traces of other products are also formed) and Hop-bracts (studded with yellow glands containing a bitter substance, lupulin) to make the infusion keep as well as to make it bitter, the alleged adulterants of beer are mostly far too costly to be used

Wine is made from various substances besides Grapes—Gooseberry, Currant, and Elder fruits, Cowslip flowers, Oranges, Ginger, Rhubarb, etc., cider from Apples, perry from Pears

Distilled spirits include brandy (distilled from wine or potatoes, with addition of prunes, burnt sugar, etc), whisky (when pure, distilled from grain and flavoured by traces of creosote from wood or peat smoke used), gin (flavoured with essential oil of Juniper fruit, or with turpentine, often with addition of sugar, oils of cinnamon or cloves, etc), rum (distilled from molasses, coloured with burnt sugar, flavoured with Pineapple, etc), absinthe (an unwholesome liqueur, flavoured with Wormwood).

(2) The chief **condiments**, which contain volatile essential oils (some have been artificially synthesised), are Mustard (ground seeds), Pepper (ground akenes, white or black if the pericarp is removed or left on), Cayenne and Chillies (capsules of *Capsicum*, Solanaceae), Capers (flower-buds of *Capparis*—unripe capsules of *Tropaeolum* often substituted), Horse-radish (roots), Fennel (leaves), Garlic (bulbs), Parsley, Dill, Cummin, Anise, Fennel, and other Umbellifers with aromatic fruits; various aromatic pot-herbs of the Labiate family (Mint, Sage, Thyme, Basil, Marjoram, Savory), of which the leaves are used, usually dried; Ginger (dried rhizome of *Zingiber* and allied tropical plants).

(3) The chief **flavourers** and **spices** are Nutmegs (seeds of Myristica), Mace (aril of Nutmeg-seed), Allspice (dried berries of *Pimenta*, West Indies), Cloves (flower-buds of *Eugenia caryophyllus*), fruits of Caraway, Coriander, and Angelica (Umbellifers), Peppermint (leaves distilled for oil), Cinnamon and Cassia (bark), Vanilla (capsule of Vanilla-orchid) is costly, but the essential substance vanillin is prepared cheaply from coniferin (present in cambium of Conifers) and other compounds

(4) Most **alkaloids** are used in medicine, but in several vegetable products their action is modified by the presence of other substances; Tea (leaves of *Thea viridis* and its varieties), Coffee (seeds of *Coffea*), and Cocoa (berries of *Theobroma*) contain them, caffein, and theobromin respectively—almost identical alkaloids—along with tannin and oils, Kola seeds and Holly leaves are also used, the former resembling Cocoa and Coffee in composition, while the latter form a fair substitute for tea

656. Miscellaneous Materials.—Many other vegetable materials are used which hardly come under any of the headings already given, *e g* the bath-loofah, consisting of the vascular bundles of the fruit of a tropical Gourd (*Luffa*, very like that of Cucumber), after soaking to remove the soft tissue

Graphite, used for lead-pencils, etc., is found in beds and was doubtless formed from the earliest plants to appear on the earth—it consists of carbon.

QUESTIONS ON CHAPTER XXVIII

1. Describe the structure (naked-eye features) of a block of Pine-wood, with the bark, cut so as to show the radial and tangential faces.

2. What is meant by "silver grain" in wood?

3. How are knots formed in timber, and how do they differ from the rest of the wood?

4. How can you tell whether a surface of wood is cut transversely across the stem or radially or tangentially along the stem?

5. Describe the two sets of surfaces seen in a square Pine match.

6. How can you distinguish between the following timbers in the natural state (*i.e.* not stained, varnished, or polished)?—Pine (deal), Oak, Walnut, Lime.

7. What trees supply timber for the following purposes, and why are these timbers chosen in each case?—telegraph-poles, piles and piers, fine carvings, floors of houses, oars, shipbuilding, turnery work.

8. How is cork formed? What tree supplies commercial cork? Describe the naked-eye structure of cork, and point out how it differs from wood.

9. Name the chief fibres used in commerce (excluding cotton), and mention in each case the plant which yields the fibres, the part in which they occur, and their use to the plant.

10. What is "raw" cotton? From what plant is it obtained? What are the cotton-fibres, and what is their use to the plant?

11. What plants yield dyes, and from what parts are the dyes extracted?

12. What plants yield tanning materials? In what parts of plants is tannin contained, and of what use is it to the plants?

13. Name the chief kinds of vegetable oils, and the plants, and parts, which yield them.

14. What are resin and turpentine, and from what plants are they obtained?

15 What is rubber? What is latex? What plants have rubber-yielding latex?

16 From what plants, and from what organs, is starch usually obtained? What plants yield cornflour, sago, arrowroot, and tapioca?

17 What plants yield sugar? Which plants contain (*a*) cane-sugar, (*b*) grape-sugar? How can these two sugars be distinguished?

18 Which part of the plant is eaten in the following cases, what is the nature of the food-material, and what part does it play in the plant's life?—Potato, Jerusalem Artichoke, Turnip, Carrot, Parsnip, Beet, Onion, Scorzonera, Spinach, Brussels Sprouts, Cauliflower, Celery, Asparagus, Globe Artichoke, Water-cress, Common Cress, Mustard, Endive, Mint, Tomato, Cucumber

19 Describe the structure of the following fruits —Apple, Pear, Quince, Plum, Cherry, Apricot, Peach, Nectarine, Almond, Grape, Raisin, Currant, Orange, Lemon, Date, Pomegranate, Banana, Strawberry, Blackberry, Fig, Pineapple, Mulberry.

20 Describe the following "nuts" —Hazel, Walnut, Brazil, Sweet Chestnut, Coco-nut, Pistachio

21 Describe the following, stating in each case the part of the plant used —Black Pepper, White Pepper, Mustard (ground), Cayenne, Chillies, Capers, Fennel, Ginger, Nutmeg, Mace, Cloves, Caraway, Cinnamon, Manilla, Tea, Cocoa, Coffee

22 What is the nature of the following?—a bath-loofah, a lead-pencil, otto of roses, a bamboo-cane, a wicker basket, a clothes-line, a mast or flag-pole, a Panama hat, peppermint, linseed-oil, olive-oil, charcoal, coal, wood-paving, resin, macaroni

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